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RESTORING THE WILLAMETTE RIVER:

COSTS AND IMPACTS OF WATER QUALITY CONTROL

by

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ABSTRACT

The means by which the water quality of the Willamette River has been upgraded over the past four decades are documented. Two strategies --point-source wastewater treatment and flow augmentation from a network of federal reservoirs--have been responsible for this improvement in water quality. The series of tactics employed in gradually reducing point-source waste discharges are documented. Coincident water quality benefits which have resulted from flow augmentation for other purposes are also discussed.

The economic and energetic costs of constructing, operating, and maintaining the facilities which have significantly contributed to the improvement of water quality in the Willamette River and its tributaries over the last half century are examined. Data are presented regarding the construction and operation of municipal collection and treatment systems, industrial water pollution abatement facilities, and reservoirs. Input-Output economics and a methodology for converting dollar costs to direct and total energy requirements are used to deal with construction and operational costs. Operation and maintenance expenditures are also dealt with on the basis of direct at-site requirements. Energy needs for operating water quality control facilities are about one-tenth of one percent of total basin energy utilization. Substantial savings of this energy are possible, however.

Historic and current status of the fishery and wildlife resources of the Willamette River Basin are reviewed in relation to changing water quality of the River. Recent improvements in water quality have stimulated State and Federal agencies to embark on a nine-year program to fully develop the fishery resources of the Basin. The potential biologic, economic, and social values of the program are presented along with related adverse effects attributed to water quality improvement procedures.

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SECTION I

CONCLUSIONS

1. Two pollution control strategies are essential to maintain the water quality of the Willamette River. First, at-source wastewater treatment must be required at a level sufficient to keep the absolute pollutant loading of the river within limits that will allow the meeting of water quality standards. Second, flow augmentation is required to provide a sufficient volume and depth of water to maintain desirable waste dilution, stream temperatures, and dissolved oxygen concentrations.

2. Future population growth and/or industrial expansion that generate additional wastes will unbalance the present water quality status. Thus, higher levels of wastewater treatment, greater augmentation flows from upstream reservoirs, or some combination of these measures will be required. Many possibilities for altering wastewater treatment levels are available as many of the industries which have contributed the largest pollution loads (e.g., pulp-and-paper mills) have independent wastewater treatment facilities and several others (e.g., food processors) could provide various measures of pre-treatment or could separately treat and dispose of wastes which now enter municipal systems (as already done to a limited extent). The possibility also exists for greater flow augmentation from existing impoundments (at the cost of reducing other reservoir benefits) or from impoundments constructed in the future.

3. Very few data exist regarding the energy costs of goods and services. The ability to accurately evaluate the total energy commitment associated with the improvement of water quality in the Willamette Basin is therefore limited.

4. Capital energetic costs are important factors in the consideration of total annual project costs. The total capital energies (at-site construction energy requirements plus the energy required to produce the materials and equipment incorporated in the finished product) of a treatment facility can exceed the facility's lifetime operational energy requirements.

5. In estimating the energy costs of constructing water pollution control facilities in the Willamette Basin, less than 10 percent of the total is reflected in the direct on-site needs of a constructor. Much energy is embodied in the materials and process equipment which are required for any project. This is particularly true of wastewater treatment facilities. Thus an estimate of the direct construction energy requirements is not a sufficient measure upon which to judge the total energy impact of building a facility.

6. Electricity used in operating and maintaining water quality control facilities represents about 480 Tera Joules (TJ) (140 x 10^6 kilo-Watt·hours (kW·hr)), or nearly seven-tenths of one percent of the total electrical needs of the Willamette Basin. Large energy savings could be made by properly designing collection and treatment systems or by relying more heavily upon nature's assimilative capacities.

7. Wastewater lift station costs, particularly energy expenditures, are important considerations in municipal wastewater control. Pumping of municipal wastewaters in the Willamette Basin consumes about 25 percent of the energy used in collecting and treating these flows. Some Willamette Valley cities use more energy pumping flows than in treating them.

8. Post chlorination of municipal wastewater requires large inputs of energy. The energy required to produce the chlorine used for this purpose is equal to between 40 and 50 percent of the electrical requirements of operating all the municipal treatment facilities in the Willamette Basin. However, over-application accounts for a large portion of this value and a large savings of resources could be realized by proper surveillance of this practice.

9. Low flow augmentation by the federal reservoir system plays an important part in the water quality management picture of the Willamette Basin. The water quality control portion of the reservoir costs, briefly estimated, is equal to less than 10 percent of the capital and one percent of the operational investments made by municipalities and industries combined.

10. In the past, poor water quality has impeded full development of the fishery and recreational resources of the Willamette River Basin. Maintenance or continued improvement of current water quality standards are a necessary element in the goal of producing an additional 180,900 salmon and steelhead worth in excess of $2,398,000 annually. Other recreational and aesthetic resources of the River benefit from water quality improvements. The aesthetic and biologic costs of wastewater treatment activities seem minor compared with overall benefits.

SECTION II

RECOMMENDATIONS

1. Due to the overlapping of tactics, it was not possible to separately assess the impact of each pollution control technology applied to wastewater treatment using actual water quality data obtained for the Willamette River. The separate influences of different wastewater treatment technologies can be estimated by use of the recently developed U. S. Geological Survey's Willamette River water quality simulation model. The water quality associated with each tactic and its corresponding pollutant loadings should be evaluated using this model.

2. Flow augmentation was found to have a highly significant influence over summer-autumn water quality in the Willamette River. However, the actual augmented flows varied irregularly and were generally greater than target flows at control points along the Willamette. The effects of flow augmentation need to be investigated in a more systematic manner than from historic data alone. By use of the U. S. Geological Survey's water quality simulation model, various levels of flow augmentation can be studied for their influence on river water quality. This should be done in conjunction with the simulation of different wastewater treatment tactics in order to more fully explore alternative means of pollution control.

3. Energy analysis, the association of energy values with various goods and services, requires a definite commitment of research effort in the future. In the construction industry this might include close surveillance of on-site energy needs for various activities.

4. Increased investigation of wastewater treatment operational parameters should be undertaken. This work should focus on other than mainline treatment. For example, sludge handling and disposal are becoming increasingly important; but relatively little, other than pilot plant and demonstration facility data, is known about the costs and benefits of this treatment.

5. Chlorine application should be researched in depth and closely monitored by regulatory agencies. Chlorine production is highly energy intensive and a substantial reduction in its use would yield significant energy savings. This fact, along with chlorine's counter-productive instream biological effects and possible carcinogenicity, clearly shows the need for further research. This work should include evaluating the need for bacterial reduction as well as evaluating alternative means by which this reduction might occur.

6. A comprehensive look at wastewater collection and treatment, as they relate to each other and as they relate to other factors such as transportation, land use, and air quality, is needed. For example, large regional treatment facilities requiring long interceptor lines and pumping of flows should be carefully evaluated. While economies of scale may be realized in the treatment end of this work, the resource allocation for the total system could be greater than that required for an alternative system of several smaller, local plants.

7. Further research of cost allocation in multi-purpose projects such as reservoirs is needed. This work should include the evaluation of negative impacts as well as normally considered benefits and should not be limited to solely economic considerations.

SECTION III

INTRODUCTION

BACKGROUND

The Willamette River during the first half of the twentieth century was described as a "stinking", "ugly" and "filthy" river--an "open sewer" of untreated sewage and wastes. At times the condition of the Willamette was so "intolerable" that workmen even refused to work on river-side construction near sewer outfalls.[1] Portland citizens spear-headed efforts to bring the deplorable state of the river to the attention of city, county and state officials. But little or no response resulted. The worsening situation, documented by water quality tests conducted by the Oregon State Board of Health and concern expressed by the U. S. Public Health Service, only slowly made inroads on legislative inertia. Additional support from public groups and the League of Municipalities, backed with further data from surveys by the Engineering Experiment Station (Oregon State University (OSU)--then Oregon Agricultural College), Oregon State Board of Health (OSBH), and Oregon Fish and Game Commission, drew administrative response from the Governor's office, but still no effective legislative action. Finally, in the face of continued inertia from the State Legislature, the citizens of Oregon passed an initiative measure in November, 1938, by a resounding majority vote, to create the Oregon State Sanitary Authority (OSSA).

The period from 1939, and especially since the end of World War II, until the end of the 1960's is one of increasing determination and accomplishment in abating the pollution of the Willamette River.

Today, because of an aroused citizenry and concerted efforts by local, state and federal groups, the Willamette River meets demanding water quality standards throughout its length. It stands out nationally as an example of a "river returned", a "new river". Although not pristine, the Willamette River has been restored to a cleanliness unknown since the last century--probably close to that encountered by early white settlers.

The Willamette River of today offers a broader spectrum of recreational and scenic opportunities for the people of Oregon than it has known for several decades. Granted that technological development makes possible many types of recreation unknown to our forefathers, the fact remains that for over half a century the river was too badly polluted along many parts of its length to encourage swimming, boating, hunting, fishing, or even viewing--all of which are today enjoyable in those same locations. Plans and programs for river-related activities, such as the Willamette Greenway concept throughout the Willamette Valley or the Johns Landing urban redevelopment near downtown Portland, can at last be predicated upon the high water quality of the Willamette River.

There have been significant benefits of cleaning up the Willamette River to both Oregonians and the nation. The example offered by the Willamette may be repeatable elsewhere in similar basins in efforts to provide "quality" environments. But the costs of retrieving a "nearly lost" river are also great and these too must be considered and evaluated. Expenditures of large magnitude had to be made in money, manpower, materials and energy in order to return the river to its present desirable condition. Such expenditures continue year after year so that the quality of the river may be maintained and improved. The benefits of pollution abatement have been described in many ways to the public; hence programs of pollution control have strong citizen support. The direct, obvious costs of water quality protection, such as the costs of pollution control facilities, are generally known. But pollution control has less-direct, less-obvious costs which must also be known. For example, a network of flood control reservoirs provide substantial water quality benefits through the conservation releases made during the non-flood season; these benefits are not really free but are inherent in the costs of constructing, operating and maintaining these facilities. Similarly, the removal of wastes from municipal and industrial sewage treatment systems before effluents enter the Willamette River or its tributaries is accomplished at the cost of producing equipment and chemicals (and pollution) elsewhere for use in these treatment systems and at the cost of producing pollutants at these treatment systems that are disposed of onto land or into the atmosphere. Realistic evaluation of water pollution abatement must include benefits and costs which extend beyond the waters of the Willamette River and its tributaries and the waste treatment plants which line their banks. From a broader perspective, a clearer picture emerges of the true benefits, costs and impacts of water quality improvement for a river basin.

The 1970's have fast become an "energy-conscious" decade. Energy problems faced by the nation have led us, as never before, to evaluate the energy costs of doing things. Pollution control facilities of all types require considerable expenditures of energy for their construction, operation, maintenance, expansion, and modernization. The Willamette River "clean-up", therefore, has required the use of a gread deal of energy. But, hithertofore, no study has been made of the magnitude of such an energy expenditure to abate pollution in the Willamette River Basin, or, for that matter, any other river basin.

This report addresses the question of energy expenditures required to restore the water quality of the Willamette River. The energy costs are described and documented to that extent possible during the study period with available information and the analyses made therefrom. Hopefully, the results reported and conclusions drawn will help fill a significant gap in the broad-perspective picture needed for water quality improvement in a river basin.

PURPOSE OF STUDY

The purpose of the study reported here has been to describe and document, insofar as possible, the energy costs of the pollution control techniques that have been used to restore the water quality of a river basin. The Willamette River is used because it is one of the largest rivers in the United States (ranking 12th in size) where a highly significant restoration of water quality has been accomplished. Documentation of the clean-up is excellent and thus a meaningful analysis can be attempted. The energy requirements of an undertaking such as cleaning up a river can in many respects be determined from study of the economic costs of the required facilities. Coupled with economic costs and energy expenditures are a variety of environmental impacts. Further, the accomplishment of pollution control itself produces many environmental impacts. Therefore, in treating the subject of energy costs of pollution control, it is necessary to determine economic costs. Furthermore, it is important to address the environmental impacts in order to provide a measure for the justification of economic and energy expenditures in river clean up.

Four objectives have been pursued to fulfill the study goal. These objectives are:

1. To document the pollution control strategy that has been employed to date in improving the water quality of the Willamette River and to determine the contribution each control technology has made to the improvement of water quality;

2. To determine the total costs and annualized costs of construction and operation and maintenance for the pollution control facilities that have been employed in the Willamette Valley;

3. To determine the total energy consumed by all of the pollution control facilities that have contributed to the improvement of water quality in the Willamette River, including energy costs of constructing and operating dams (where appropriate) as well as treatment facilities and control devices; and

4. To determine the cumulative environmental impact of utilizing the pollution control strategy employed in the Willamette Basin.

SCOPE

The study included and was limited geographically to the Willamette River Basin. The time frame for the study extended from the early 1900's through 1974. During this time, the Willamette River experienced first a period of declining river quality accompanied by no attempts at pollution abatement, then a period of organization to confront the pollution problem, and finally a period of restoration of river quality. By 1972, the present degree of restoration of river quality had been virtually achieved. In the following two years the principal efforts have been aimed more at the maintenance of river quality, through improved monitoring, surveillance and enforcement, than at greater degrees of restoration. However, future strategies to fulfill stated national Water quality goals appear to be in the offering, and the present thus provides a benchmark for surveying what has been accomplished and the cost of accomplishment in anticipation and preparation for the future.

The choice of the Willamette Basin for such a study is important for several reasons. First, the river exhibits a history of decline and near-total restoration of water quality. Second, there exists support documentation regarding input pollution loads, river flow conditions, and river quality over a long period of time. Third, the basin is large and complex, yet manageable, so that lessons learned from it will find applications to many other basins. Fourth, no one has documented in an integrated manner the economic, energetic and environmental costs of the water quality improvement program. Fifth, the Willamette is one of the largest rivers in the United States where such a dramatic increase in water quality has occurred throughout the river system. Sixth, because of the successful clean-up of the river, much national interest and attention has been focused on the Willamette Basin in recent years. And, finally, Oregonians collectively appear at the forefront as regards many environmental concerns; therefore, the measures, costs and benefits which the people have demanded or accepted to abate water pollution are instructional in considering similar efforts elsewhere.

In fulfilling the objectives stated above, limitations were set as to what types of facilities would be investigated as well as the kinds of expenditures for each facility. The economic and energetic costs of designing, constructing, operating, and maintaining portions of municipal wastewater collection and treatment systems, selected industrial water pollution abatement facilities, and federal reservoirs were researched. Municipal collection was limited to that portion of the system designated as interceptor. The research of industrial expenditures was limited to larger companies having self-operated treatment facilities. Reservoir research excluded those operated by private industry and utilities.

STUDY APPROACH

The nature of this study has demanded considerable knowledge of the behavior of the Willamette River, including its hydrology, its quality, and the aquatic life it supports. In some respects, the river serves primarily as a transportation and conveyance system. Yet the river system is a habitat for an abundant aquatic life and serves as a recreational playground for many of the 1.4 million Oregonians who reside in the basin. Consequently, the study had to be approached from several perspectives.

The study team included three faculty members and a research engineer supported by graduate and undergraduate research assistants. Peter C. Klingeman, Associate Professor of Civil Engineering, a water resources engineer with a background in hydrology and hydraulic engineering, led the study. Working with him was E. Scott Huff, a research civil engineer with a Master of Science in Sanitary Engineering. Herbert H. Stoevener, Professor of Agricultural and Resource Economics, and Howard F. Horton, Professor of Fisheries, both participated in the study from their broad backgrounds in environmental impacts of human activities on water resource systems and their specific, extensive backgrounds in natural resource economics and aquatic ecosystems, respectively. Support was provided by Kenneth A. Hanson, graduate research assistant in Agricultural and Resource Economics, and Charles B. McConnell and Darrel Gray, graduate students in Fisheries. Frank D. Schaumburg, Associate Professor of Civil Engineering, was a consultant to the study, contributing from an extensive background in sanitary and environmental engineering. Richard J. Heggen, Instructor in Civil Engineering, provided considerable technical assistance to the project in data evaluation and computer services, including the evaluation of water management computer programs for the Willamette River. Eugene A. Gravel, undergraduate student in Civil Engineering Technology with several years of construction experience, contributed in the evaluation of resource expenditures involved in construction activities.

The work conducted under objective 1 was based on examination and analysis of historical descriptive material and data contained in several reports and agency documents. Responsibility for this phase of the study was held by Klingeman and Huff.

The study activities necessary to meet objectives 2 and 3 involved extensive analysis and interpretation of construction, operation, and maintenance records for wastewater control facilities and dams. Methods had to be devised in many instances in order to extend data from such records into forms usable to describe dollar costs and energy costs. Responsibility for the work was held by Huff, Stoevener, and Klingeman.

The direct environmental impacts resulting from pollution control in the Willamette River were determined under objective 4 with greatest attention given to the impact of changed water quality caused by waste treatment facilities and supporting attention given to the impact of changed hydrologic regimen of the river due to regulation by upstream reservoirs. Horton bore principal responsibility for documenting most of the work carried out under this objective, with support from Huff and Klingeman.

SECTION IV

THE WILLAMETTE BASIN STUDY AREA

GEOGRAPHICAL FEATURES

The Willamette River Basin, shown in Figure 1, encompasses an area of Western Oregon of 29,676 square kilometers (km^2) (11,463 square miles (mi^2)).[2] The basin is approximately rectangular, but in the shape of an arrowhead 240 kilometers (km) (150 miles (mi)) long by 120 km (75 mi) wide. The valley lies between the Coast Range, to the west, and the Cascade Range, to the east. The two ranges extend southward to converge at the Calapooya Mountains and extend northward to the Columbia River. The Willamette Valley may be described in geological terms as a structural depression or downwarp with hills of moderate relief in places separating broad alluvial flats.[3] The valley floor consists of lake deposits and other consolidated and unconsolidated alluvium and covers about 9100 km^2 (3500 mi^2) with limiting dimensions of 200 km (125 mi) by 50 km (30 mi). Alluvial fans along the edges of the valley extend from the volcanic and sedimentary formations which comprise the surrounding mountains. Basin elevations range from 3 meters (m) (10 ft (ft)) mean sea level (msl), along the Columbia River to 120 m (400 ft) on the valley floor at Eugene to 1200 m (4000 ft) in the Coast Range and above 3000 m (10,000 ft) in the Cascade Range.

The Willamette River drainage system is shown in Figure 1. Formed by the confluence of the Middle and Coast Forks near Eugene, the river has a general northward course. Numerous tributaries enter from both the Coast Range and the Cascade Range. The streams from the west side of the basin have considerably smaller drainage areas and less-sustained summer flows than those originating in the Cascade Range. The Willamette River and its main tributaries (in their lower reaches) have broad floodplains and meander belts. Meandering diminishes in the northern part of the basin where the rivers are somewhat more confined by adjacent topography. The main stem includes short riffles, long deep pools, the falls at Oregon City, and a tidal reach between the falls and the mouth.

BASIN CLIMATE

The Willamette Basin climate is characterized by warm, dry summers and mild, wet winters. The nearby Pacific Ocean dominates the weather pattern whereas the Coast Range, Columbia River Gorge and Cascade Range

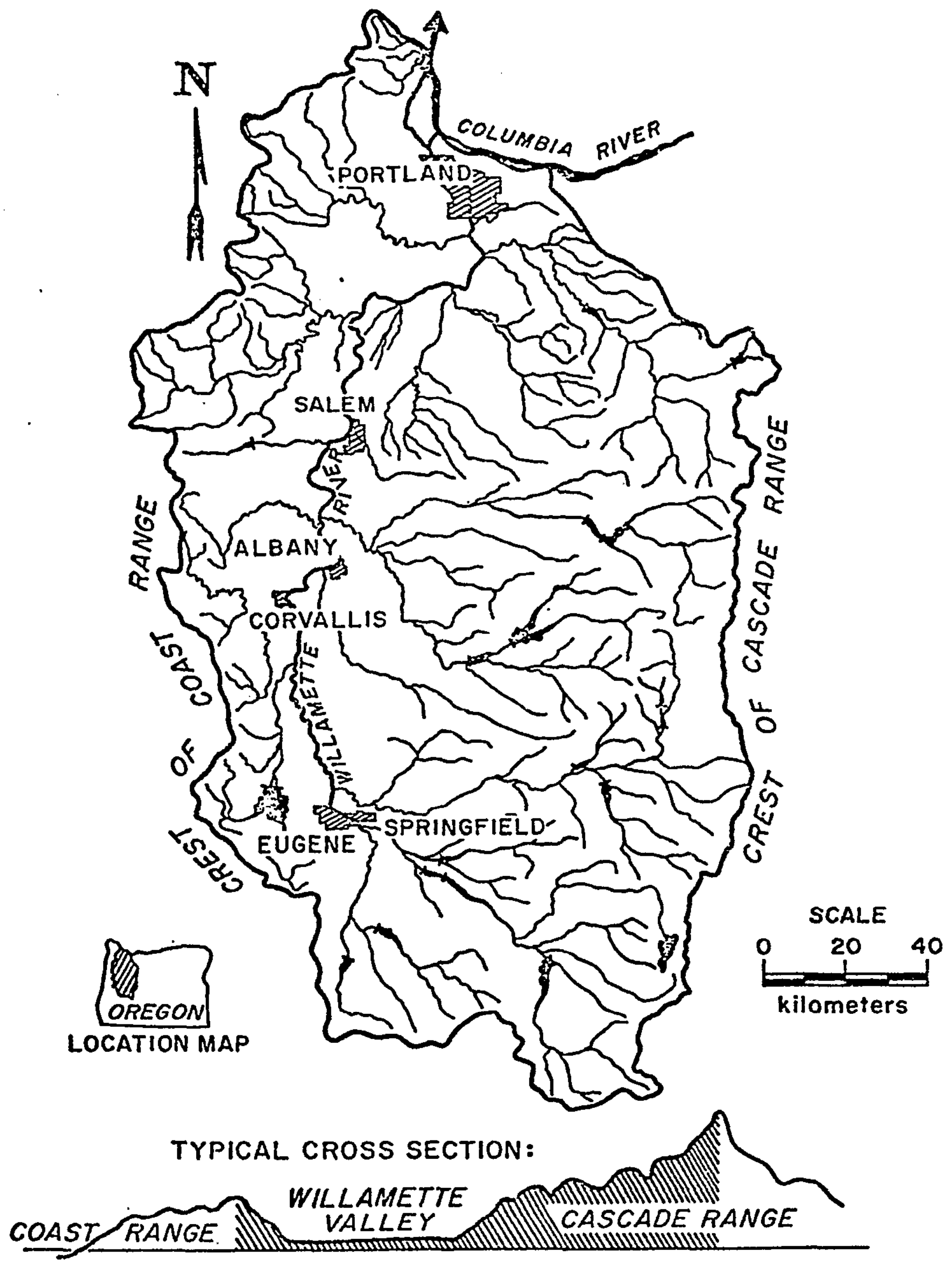

Figure 1. Willamette River Basin

have modifying influences. Annual precipitation varies from 0.9 m (35 inches (in)) on the valley floor to well over 3.3 m (130 in) in portions of the mountain ranges, with a basin average of 1.6 m (63 in).

Approximately 70% of the precipitation occurs between November and March. Temperatures on the valley floor range from a monthly mean of about 4°C (40°F) in January to about 20°C (70°F) in July. Daily temperatures seldom drop below -20°C (0°F) or rise above 40°C (100°F).

Typical monthly values of air temperature and precipitation at Salem, together with Willamette River streamflow and water temperature there are shown in Figure 2. Salem is centrally located on the valley floor (see Figure 1), its climatic and runoff features are representative for the valley, and the climatic and hydrologic records are of comparatively long duration.

RIVER HYDROLOGY

Runoff closely follows the annual precipitation pattern of the basin. Streamflows usually peak in December, January or February and normally reach minimum levels in late summer (see Figure 2). A lesser spring runoff peak corresponds to gradual snowmelt from the higher elevations of the Cascade Range. Stream temperatures generally reflect the pattern for air temperature, as modified by snowmelt runoff (Figure 2).

The main stem originates at the confluence of the Coast and Middle Forks 301 km (187 mi) from its mouth and at an elevation of about 130 m (430 ft), msl. Major tributaries are the McKenzie, Santiam, and Clackamas Rivers, all draining the Cascade Range and foothills, and the Yamhill River, draining Coast Range slopes (see Figure 3). Tributaries from the east have higher base flows in summer months than those from the west, due to melting snow and groundwater storage.

The average annual runoff at successive points along the main-stem Willamette River and from principal tributaries is shown in Table 1. U. S. Geological Survey streamgaging stations provide the reference points for data.

The total Willamette Basin runoff, averaging 30 billion m^3/yr (G m^3/yr) (24 million acre-feet per year), places the river as 12th largest in the United States.

NATURAL RESOURCE USE AND DEVELOPMENT

Almost two-thirds of the Willamette Basin is forested. These lands are predominantly in upland areas. The valley floor and adjacent lands are predominantly devoted to agricultural and grazing uses--about one-third of the basin area. Urban zones and local areas of forest are

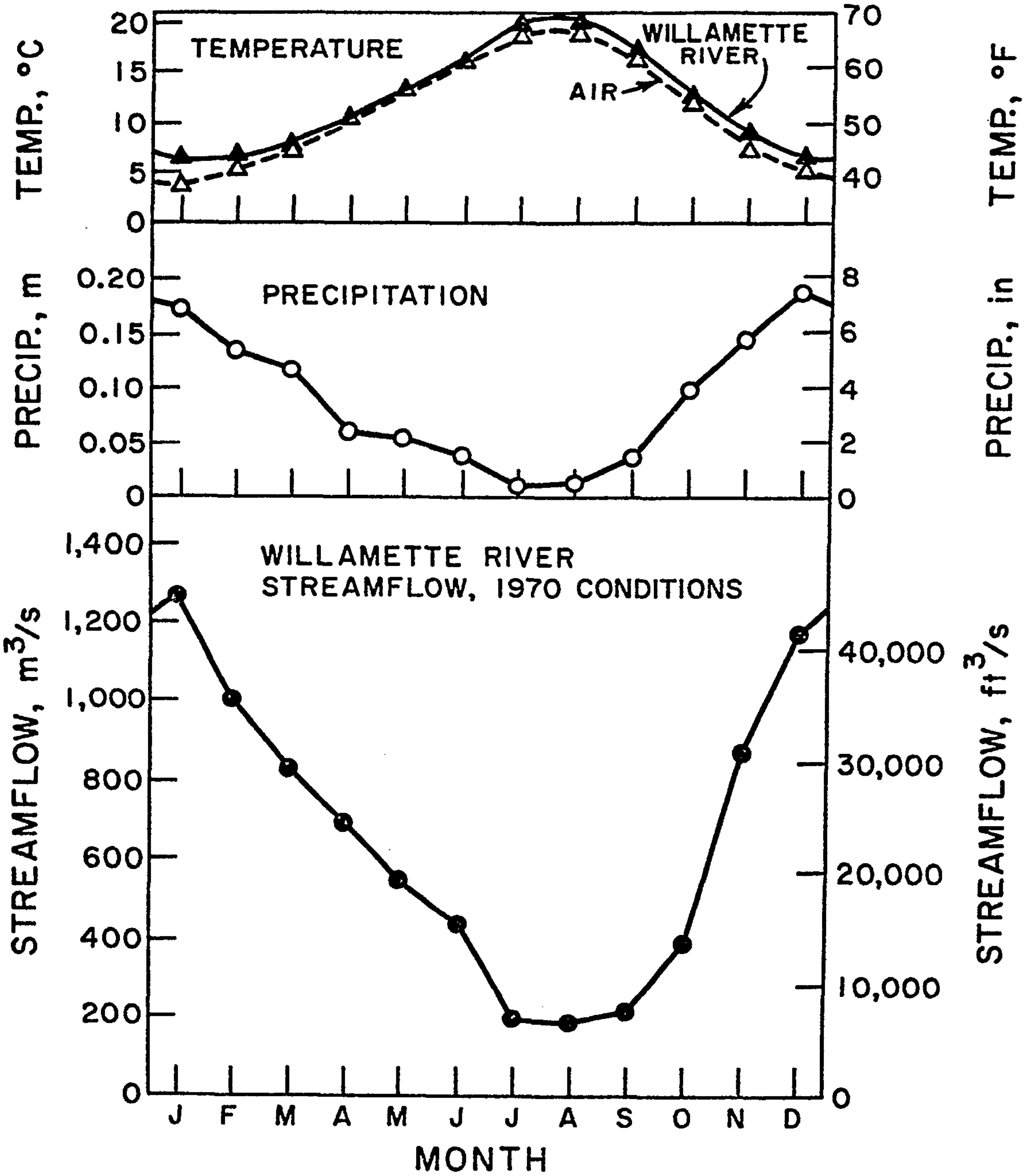

Figure 2. Typical patterns for climatic and hydrologic variables at Salem, Oregon.[2]

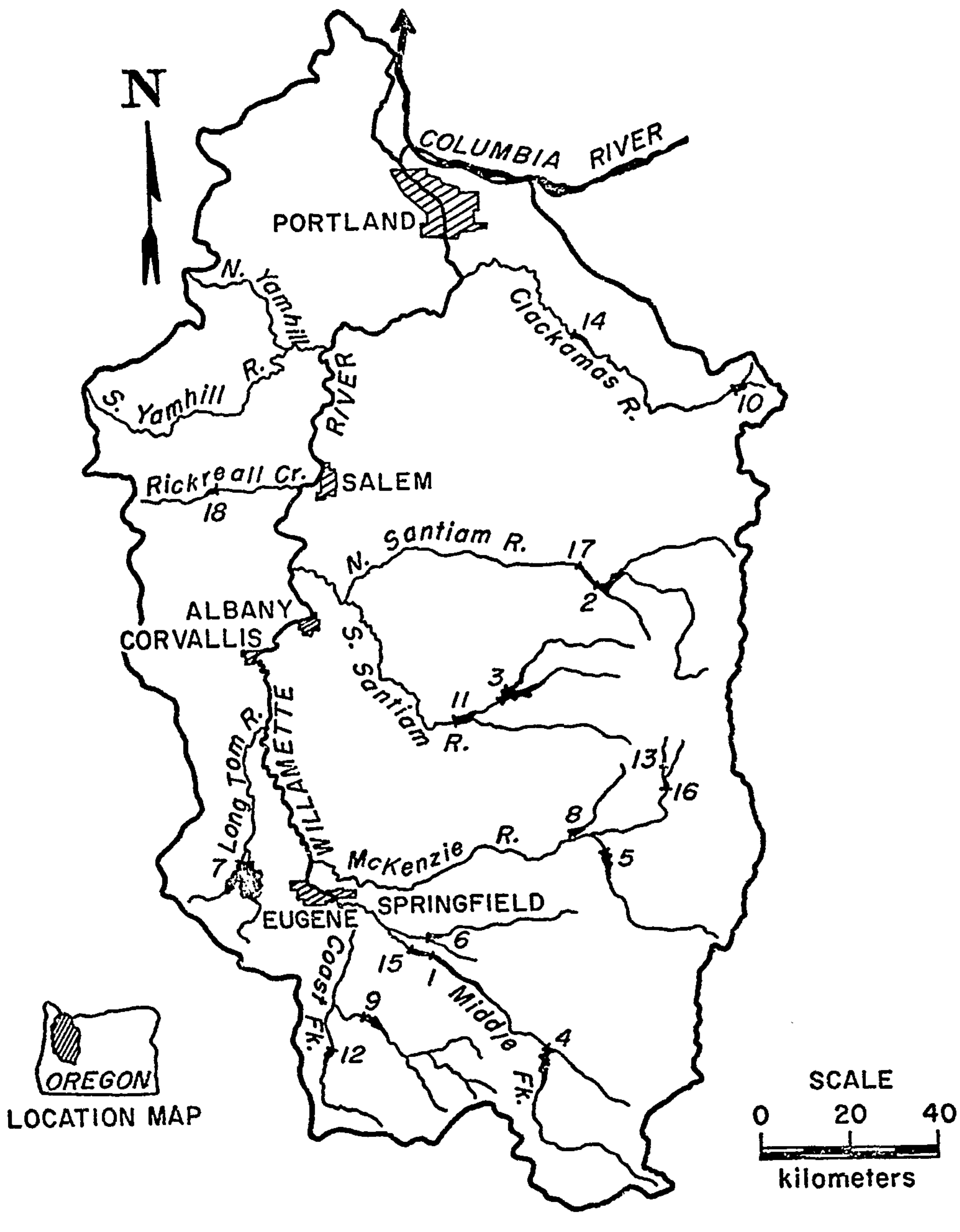

Figure 3. Principal Willamette Basin Reservoirs.

Table 1. AVERAGE ANNUAL RUNOFF FOR THE WILLAMETTE RIVER AND PRINCIPAL TRIBUTARIES[a]

Stream and locations	Drainage area		Average annual runoff: Rate		Average annual runoff: Volume	
	km^2	mi^2	m^3/s	ft^3/s	$10^6\ m^3/yr$	acre-foot/yr
Tributaries						
Coast Fork Will. R. nr. Goshen	1,660	642	48	1,680	1,500	1,220,000
Middle Fork Will. R. at Jasper	3,470	1,340	112	3,970	3,540	2,870,000
McKenzie R. nr. Coburg	3,461	1,337	153	5,400	4,820	3,910,000
Long Tom R. at Monroe	1,010	391	22	780	700	565,000
Marys R. nr. Philomath	412	159	13	460	410	333,000
Calapooia R. at Albany	963	372	26	910	810	659,000
Santiam R. at Jefferson	4,630	1,790	232	8,200	7,330	5,940,000
Luckiamute R. nr. Suves	620	240	25	880	790	637,000
Yamhill R. at Lafayette	1,900	735	64	2,250	2,010	1,630,000
Pudding R. at Aurora	1,240	479	35	1,220	1,090	883,000
Molalla R. nr. Canby	836	323	32	1,130	1,010	818,000
Tualatin R. at West Linn	1,840	710	42	1,490	1,330	1,080,000
Clackamas R. nr. Clackamas	2,420	936	105	3,700	3,310	2,680,000
Main Stem						
Willamette R. at Springfield	5,260	2,030	164	5,780	5,160	4,180,000
Willamette R. at Harrisburg	8,850	3,420	328	11,600	10,400	8,400,000
Willamette R. at Albany	12,500	4,840	408	14,400	12,800	10,400,000
Willamette R. at Salem	18,800	7,280	665	23,500	21,000	17,000,000
Willamette R. at Wilsonville	21,700	8,400	739	26,100	23,300	18,900,000
Willamette R. at Portland	28,700	11,100	934	33,000	29,500	23,900,000

[a] Data are for the period 1928-1963 from reference 2. For tributaries, gaging stations nearest the Willamette River are used. Some reported values are approximate.

interspersed with farming on the valley floor and foothills. Almost half of the basin land area is in public ownership (federal, state, county, municipal).

The economic development of the Willamette Basin is oriented to its natural resources. The basin is a major center for agriculture, timber production, food processing industries, including canneries, and forest products industries, including pulp and paper mills. Business, commerce, government, and learning are significant to the basin economy. Recreational activities are a major facet of basin life and are oriented to fish and wildlife, water sports and out-of-doors activities in the forests and mountains.

Extensive forests cover the majority of the Willamette Basin except on the valley floor. Elevation is the principal determinant of vegetation zones. The valley zone below the 300 m (1,000 ft) elevation level has been extensively converted to agricultural and urban uses. However, scattered forest stands of softwoods and hardwoods occur, including Douglas-fir, cottonwood, alder, Oregon ash, bigleaf maple and white oak.[4] The principal forest zone lies between 300 m (1,000 ft) and 1200 m (4,000 ft) elevations, where much of the timber resource is harvested. Extensive pure stands of Douglas-fir predominate over western hemlock, western red cedar and the true firs. The upper slope forest zone, between 900 m (3,000 ft) and 1,800 m (6,000 ft) elevations and marked by precipitation ranging from 2.3 m (90 in) to 3.6 m (140 in) annually, is primarily commercial forest. The predominant stands are true firs and mountain hemlocks.[4] Meadows, lakes, and rock outcrops are frequent in this zone. The subalpine forest zone above 1,500 m (5,000 ft) of elevation has a very short growing season (30 days). Subalpine firs, mountain hemlock, white-bark pine, and ground juniper are the principal tree species. Tree stands are scattered and mixed with meadows, barren areas and lakes.

Timber-based industries in the Willamette Basin are oriented to the unique character of Douglas-fir stands found in western Oregon and western Washington.[4] Climatic influences have provided an environment which allows a Douglas-fir vegetative system to provide large growth of relatively uniform size and age in particular stands. To sustain this timber resource, a harvesting pattern of patchcutting and clearcutting has been adopted which is highly efficient for commercial extraction.

The temperate, climate, abundant water, and fertile soil with broad capabilities have made agriculture the second most important use of land resources in the Willamette Basin after timber harvesting. On the valley floor, timber stands were removed by early habitants to provide needed space for farming. About 11,000 km^2 (4,400 mi^2) are suitable for cultivation, with 8,800, km^2 (3,400 mi^2) presently used and the remainder forested or in urban use.[4] Soil capabilities to produce crops over long periods vary. About half of the suitable land exhibits excessive wetness due to high water tables, poor internal drainage characteristics of the soil, inadequate drainage outlets, or overflow conditions. This has required crop adaptation and limits productive yields.

Principal crops include grass seed crops, the growth of which is well adapted to land wetness problems. A substantial livestock industry is supported by improved hay and pasture lands. Grain crops, chiefly wheat and barley are grown. The grain and grass crops support the livestock industry during winter months. Fruit and vegetable crops are quite important, among these snap beans, sweet corn and filberts supply a significant fraction of the nation's needs.

Mineral production in the Willamette Basin is not extensive, about $20 million annually.[4] Most of the production focuses on sand, gravel, stone and cement for the construction industry. A great deal of the sand-and-gravel needs have been met from streambeds and adjacent former channels of the valley streams. Production of metallic minerals has been mainly limited to mercury, gold, silver, copper, lead, and zinc. The total value of all such production is relatively small ($3 million since 1900).

Fish and wildlife resources in the Willamette Basin take on a significance far beyond economic importance. This has been attributed to "the pioneer heritage, which orients the Willamette resident to his natural environment" and "has remained as a part of the regional character" with fish and wildlife resources "one of the threads of the total environment that makes the Willamette Basin a desirable place to live".[4]

Resident fish abound in the streams, lakes and reservoirs of the basin. The Willamette main-stem is a migration route for a growing anadromous fish population. Wildlife species are numerous in the basin, both in lowland and upland zones. The Pacific Flyway, a major route for migratory birds, depends upon the Willamette Basin both for migrating and for wintering populations. Lowland streams, lakes, reservoirs, and wetlands are essential for resting and feeding areas.[4]

STORAGE RESERVOIRS

Thirty nine reservoirs in the Willamette Basin have usable storage capacities of 320,000 m^3 (300 acre-feet) or more. The larger reservoirs tend to be federal and the smaller ones privately or municipally owned.

The present federal development of Willamette Basin water resources includes 13 Corps of Engineers (C of E) dams and reservoirs. Ten of these function as storage projects and three serve as reregulating systems to dampen out the streamflow fluctuations caused by hydroelectric power production at dams immediately upstream. The 10 storage reservoirs are (from north to south in the basin): Detroit, Green Peter, Blue River, Cougar, Fern Ridge, Fall Creek, Lookout Point, Hills Creek, Dorena, and Cottage Grove. The 3 reregulating reservoirs--Big Cliff, Foster, and Dexter--are just downstream of Detroit, Green Peter, and Lookout Point, respectively.

The locations of these reservoirs and several private and municipal reservoirs for industrial and power storage in the Willamette Basin are shown in Figure 3. The reservoirs are numbered by order of size (largest = 1) and are described in Table 2. Most are situated in foothill portions of the Cascade Range. Fern Ridge Reservoir is the only "valley floor" project. All reservoirs have similar hydrologic and climatic settings. The watersheds have differing soils and geologic formations.

The hydrologic characteristics of the basin allow most of the flood control storage allocation at reservoirs to be used, outside of the winter flood season, for conservation storage and use. Storing normally occurs between February and May. Storage releases for navigation are designed to provide adequate water for the deep-draft navigation channel from the mouth of the Willamette upstream through Portland, for the shallow-draft navigation lock at Willamette Falls (first built in 1873), and for a shallow-draft channel from the falls upstream to the Albany-Corvallis area. Storage releases for irrigation occur throughout the growing season. Separate storage allocations for exclusive power use are included at several reservoirs. The basin power requirements exceed in-basin generating capacity and hydroelectric generation is required year-around. In late autumn of dry years, additional drafting of some federal reservoirs may be required to supplement hydroelectric generation on the Columbia River. While recreation is not an authorized purpose for most storage projects in the Willamette Basin, it is in fact a significant summer activity and reservoirs are operated to accommodate recreational interests as much as possible. Municipal and industrial storage reservoirs are commonly smaller than 1,000,000 m^3 (1,000 acre-ft) and divert water into pipeline transmission systems for delivery to the user areas.

DEMOGRAPHIC FEATURES

Principal urban centers are Metropolitan Portland, Salem, Corvallis-Albany, and Eugene-Springfield. These and smaller towns and communities are surrounded by agricultural and forested lands so as to maintain vestiges of rural setting. Transportation corridors for highways and railroads provide essential links and weave the communities together. Three-fourths of the basin residents live in urban areas; most live within 20 km of the Willamette River.[4]

Table 2. STORAGE RESERVOIRS IN THE WILLAMETTE BASIN WITH 1 MILLION CUBIC METERS OR MORE OF USABLE STORAGE[a]

Rank	Reservoir name	Stream	Operator[b]	Year placed in operation	Usable storage 10^6 m^3	Usable storage Acre ft	Authorized purposes[c]
1	Lookout Point	Mid Fork Willamette R.	C of E	1954	431	349,400	FC, N, I, P
2	Detroit	N. Santiam R.	C of E	1953	420	340,000	FC, N, I, P
3	Green Peter	Mid Santiam R.	C of E	1966	411	333,000	FC, N, I, P
4	Hills Creek	Mid Fork Willamette R.	C of E	1961	307	249,000	FC, N, I, P
5	Cougar	S. Fork McKenzie R.	C of E	1963	204	165,100	FC, N, I, P
6	Fall Creek	Fall Cr.	C of E	1965	142	115,000	FC, N, I
7	Fern Ridge	Long Tom R.	C of E	1941	136	110,000	FC, N, I
8	Blue River	Blue R.	C of E	1968	105	85,000	FC, N, I
9	Dorena	Row R.	C of E	1949	87	70,500	FC, N, I
10	Timothy Lake	Oak Grove Fork	PGE	1956	76	61,650	P, R
11	Foster	S. Santiam R.	C of E	1966	41	33,600	FC, P
12	Cottage Grove	Coast Fk Willamette R.	C of E	1942	38	30,600	FC, N, I
13	Smith	Smith R.	EWEB	1963	12	9,900	P
14	North Fork	Clackamas R.	PGE	1958	7	6,000	P, R
15	Dexter	Mid Fork Willamette R.	C of E	1954	6	4,800	P
16	Trail Bridge	McKenzie R.	EWEB	1963	3	2,750	P
17	Big Cliff	N. Santiam R.	C of E	1953	3	2,430	P
18	Dallas	Rickreall Cr.	Dallas	1960	1	1,200	M&I

[a] Data Sources: References 2, 4, and 5.

[b] C of E=Corps of Engineers; PGE=Portland General Electric; EWEB=Eugene Water & Electric Board; Dallas=City of Dallas.

[c] FC=flood control; N=navigation; I=irrigation; P=power; R=recreation; M&I=municipal & industrial. All existing Federal reservoirs are used for recreation, even though not so authorized.

The 1970 population of the Willamette Basin is estimated to be 1.4 million.[6] Its distribution within the basin among population centers is shown in Figure 4 and in Table 3. The overall population density in the central and southern part of the basin is about 25 persons per square kilometer, with maximums of about 1,200 persons per square kilometer in the largest urban centers. The overall population density in the northern quarter of the basin is about 120 persons per square kilometer (adapted from reference 4).

WATER SUPPLY DEVELOPMENT

Municipal water in the basin was provided by 78 developments in 1965. About half of these systems, serving 10% of the basin population, were based on ground water sources.[4] About 80% of the municipally-served population obtained their water from the Portland, Eugene, Salem and Corvallis surface water systems. Of these four areas, only Corvallis relies heavily on Willamette River water for the large summer demands; the others obtaining all or most of their supplies from watersheds or large tributaries of the Willamette (Bull Run Watershed, McKenzie River, Santiam River, for Portland, Eugene, and Salem, respectively). Corvallis obtains part of its supply from a municipal watershed also.

Rural domestic water supplies are primarily obtained from ground water sources.

Industrial water demands are met both from municipal systems and from independent sources. Food processing and pulp-and-paper manufacturing represent the most significant industrial water demands in the valley; the former industry is mainly supplied by municipal systems while the latter industry is almost entirely self-supplied.[4] Independent industrial systems rely both on surface water and ground water for their supply.

WASTEWATER TREATMENT FACILITIES

As of 1974 there were 130 municipal and 72 industrial wastewater dischargers operating in the Willamette Basin. While many of the smaller facilities are located on tributaries, the majority of the wastewater effluent, after treatment, is released to the main-stem Willamette River.

The principal operating municipal and industrial wastewater treatment facilities are listed in Table 4. Their locations are shown in Figure 5.

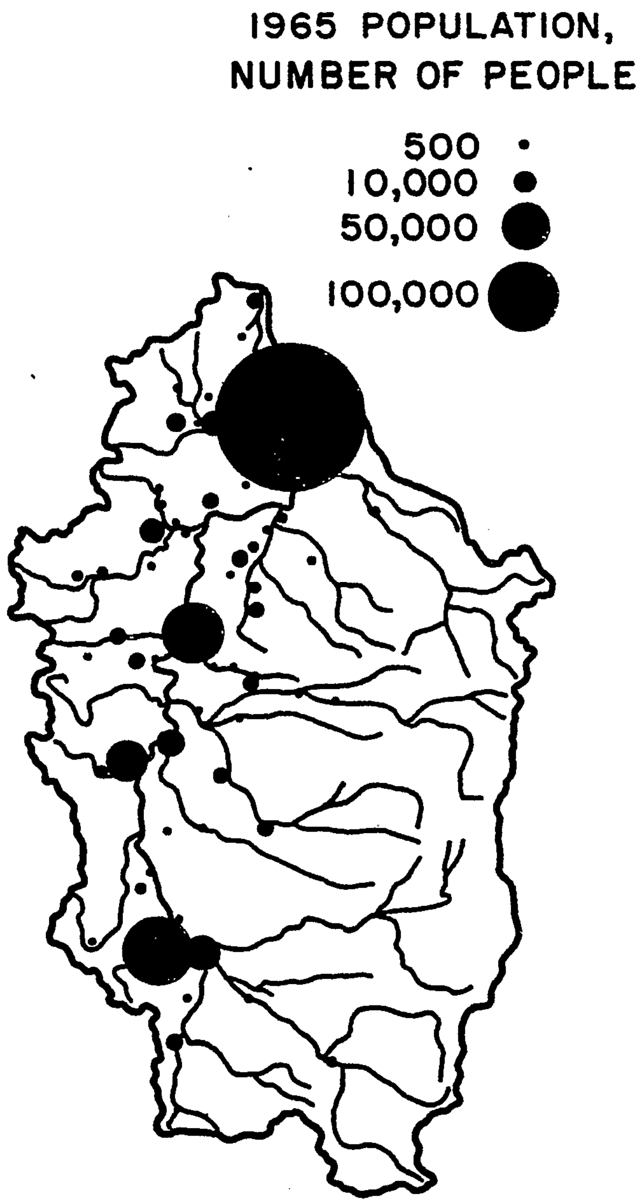

Figure 4. Population centers in the Willamette Basin.

Table 3. POPULATION CENTERS IN THE WILLAMETTE BASIN[a]

Population center	1970 population
Portland	379,967
Eugene	79,028
Salem	68,480
Corvallis	35,056
Springfield	26,874
Beaverton	18,577
Albany	18,181
Milwaukie	16,444
Hillsboro	15,372
Lake Oswego	14,615
Estimated basin population	1,400,000

[a] Source: reference 6.

Table 4. PRINCIPAL WILLAMETTE BASIN MUNICIPAL AND INDUSTRIAL WASTEWATER TREATMENT FACILITIES IN 1974.

Municipal facilities	Industrial facilities
1. Portland-Columbia Boulevard	A. Wah Chang, Albany
2. St. Helens	B. Rhodia, Portland
3. Salem	C. Pennwalt, Portland
4. Eugene	D. Evans Products, Corvallis
5. Albany	E. Boise Cascade, Salem
6. Corvallis	F. Publishers Paper, Oregon City
7. Springfield	G. Publishers Paper, Newberg
8. Portland - Tryon Creek	H. Crown Zellerbach, Lebanon
9. Fanno Creek	I. Weyerhauser, Springfield
10. Oak lodge	J. Western Kraft, Albany
11. Hillsboro - West	K. Crown Zellerbach, West Linn
12. Oregon City	L. American Can, Halsey
13. Milwaukie	M. Kaiser Gypsum, St. Helens
14. Beaverton	N. Stimson Timber, Forest Grove
15. Gresham	O. Boise Cascade, St. Helens
16. Metzger	P. Oregon Metallurgical, Albany
17. Forest Grove	Q. Union Carbide, Portland
18. McMinnville	R. General Foods, Woodburn
19. Sunset Valley	S. Tektronix, Beaverton
20. Lebanon	T. Pacific Carbide & Alloys, Portland

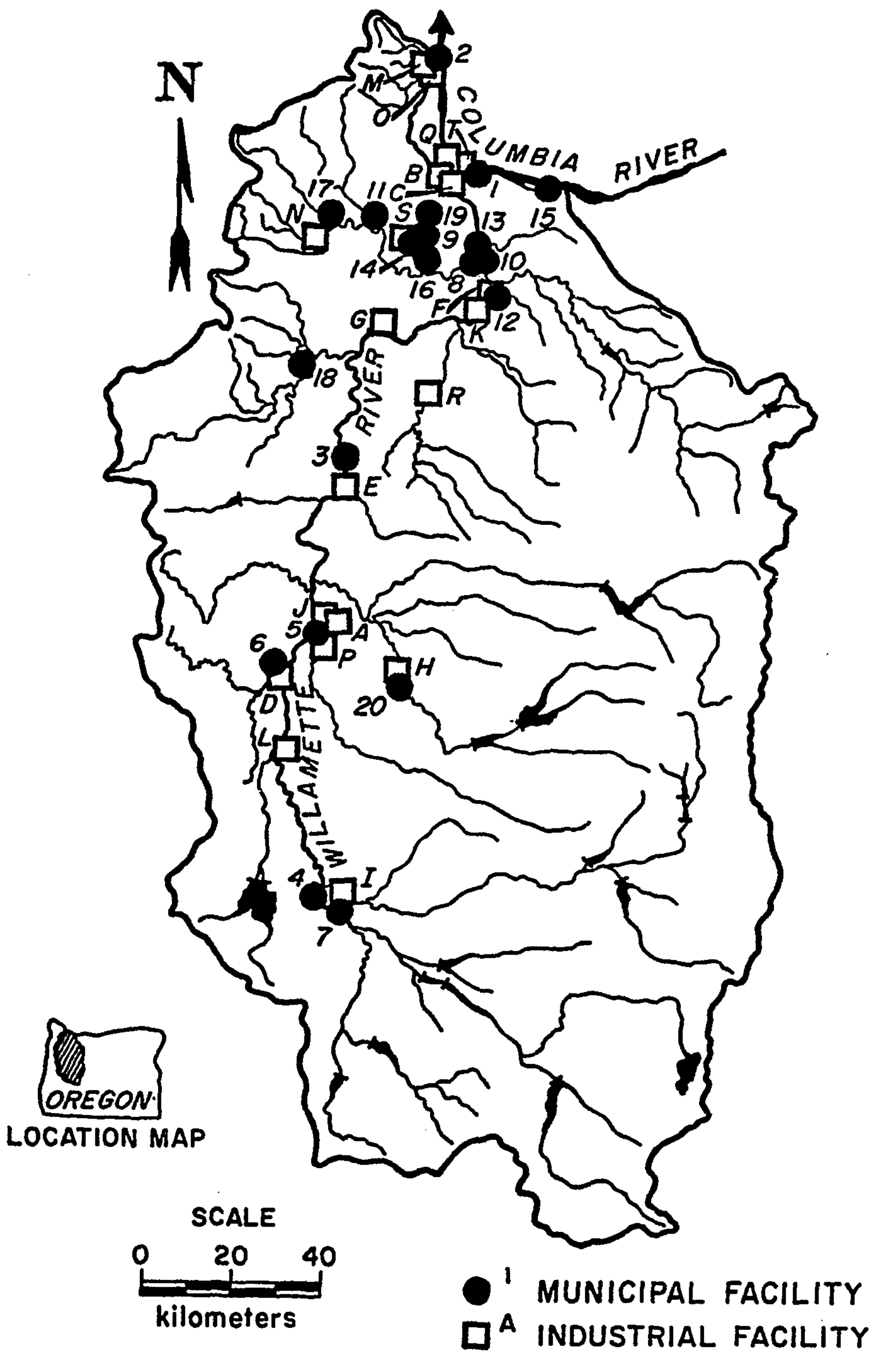

Figure 5. Principal Willamette Basin municipal and industrial wastewater treatment facilities in 1974.

SECTION V

THE STRATEGY USED TO CLEAN UP THE WILLAMETTE

DEFINITION OF TERMS

The term "strategy" finds relatively little use in legislation establishing and regulating the functions of agencies which serve the public. Its use is equally scarce in agency statements of mission, program, and goals. However, the word is becoming more common in present-day environmental planning. To describe the "clean-up" strategy used for the Willamette River, several terms must first be defined.

Strategies for water quality planning and decision-making are here considered to be the concepts and procedures followed in the comprehensive employment of available resources to accomplish set goals. Tactics are here considered to be the processes, methods, and maneuvers followed for the immediate or local employment of resources to accomplish elements of the set goals. Tactical plans and actions are subordinate to strategic plans and strategic plans are limited by tactical capabilities.

A mission is here considered to be the business with which an agency is charged or the orientation that provides focus for the agency's efforts. Thus an agency may have a developmental, regulatory, or protective mission. A goal is construed to be a statement of purpose, aim, or aspiration describing the end that the agency strives to attain; the end toward which agency effort is directed. A goal is describable at various levels of generality; its attainment is therefore often difficult to judge. An objective is a translation of a goal into a more specific, operational statement with a definite target, the attainment of which is much more readily judged. In translating a broader goal into more specific terms it may be necessary to describe several objectives so that essential, unexpressed elements of the goal are retained (i.e., several objectives may be consistent with a single goal). Objectives are associated with goals. Guidelines are here considered to be an agency's stated suggestions and recommendations for ways in which objectives can be met. Guidelines are normally expected to be followed unless deviations from the guidelines are justifiable. Principles are the ethics and rules that dictate how an agency will act and conduct itself on particular matters. Policies are guiding principles on which an agency is assumed to base a course of action that will lead toward achieving a goal or objective. Therefore, principles, particularly guiding principles (policies) must be consistent with established goals and objectives.

Tactics, then, are the actions taken by an agency in order to meet its functional objectives. Strategies, on the other hand, are more closely related to the translation of agency mission into accomplishable goals. Strategies derive from the formulation of approaches by which the goals (and hence the mission) of the agency can be met. Policies and principles express the conduct that the agency itself expects to follow in carrying out its strategies and tactics to fulfill goals and objectives. Guidelines express the non-compulsory conduct that the agency expects others to follow in order to assist the agency in carrying out its strategies and tactics to fulfill goals and objectives.

THE SEARCH FOR AN APPROACH TO POLLUTION CONTROL

The history of efforts to improve water quality in the Willamette River is given an excellent, detailed review by Gleeson[7] in "The Return of a River". Much of this work.was given broad national exposure in "The Fourth Annual Report of the Council on Environmental Quality".[8] A few salient points are summarized in the following paragraphs.

Awareness of the deplorable water quality in the Willamette River and an outcry to do something about the problem came early in the 1900's, principally from aroused citizens, the Oregon State Board of Health (created in 1903), and the U. S. Public Health Service. Chemical analyses of Willamette River water were first made in 1910. Laws related to pollution were adopted by the State as early as 1919 but were ineffectual in dealing with the pollution problems of the Willamette River. The 1920's and 1930's provided the first extensive field surveys and tests to determine the sources and severity of river pollution, with numerous reports presented. The number of advocates of pollution abatement grew during this period. The period ended with the passage of an initiative measure by the people in 1938, creating the Oregon State Sanitary Authority (OSSA). This Authority initiated its pollution abatement efforts in 1939. However, the program was delayed by World War II. Further detailed studies of river pollution were conducted by OSSA from 1944 onward and documented the worsening condition of the river through the 1950's. The absolute pollution load of the Willamette River probably was greatest by the late 1950's and early 1960's, according to indirect measures such as dissolved oxygen level (DO) and biological oxygen demand (BOD) of the river water.

Until 1935, there was nothing approaching a pollution control strategy for the Willamette River. In that year, a Stream Purification Committee under the Oregon State Planning Board was created to study, among other topics, the Oregon Law dealing with stream pollution.[7] It was found that existing laws were unrelated, uncoordinated, lacking in direct responsibility for enforcement, overlapping and duplicating, too drastic in their penal sections, probably unconstitutional in some sections, impractical of enforcement, lacking in proper delegation of administrative powers, lacking in direct control over municipalities, and impossible as regards progressive, amelioratory regulation. From a subsequent review of statutes known to be effective elsewhere, 17 "principles" were set out that should be embodied in effective anti-pollution legislation.

Thus, by 1938 a framework for an approach to pollution control existed on paper.

Meanwhile, the press of events led to the initiative measure creating the OSSA. With passage, an agency was born that was to lead the way in abating the pollution of the Willamette River.

A STATE AGENCY FOR WATER QUALITY CONTROL

Passage of the "Water Purification and Prevention of Pollution Bill" in the 1938 election created the State Sanitary Authority as a division within the Oregon State Board of Health. OSSA consisted of six members: the State Health Officer, the State Engineer, the Chairman of the Fish Commission, and three members appointed by the Governor, one from each of Oregon's three Congressional districts.

OSSA was organized in February 1939. However, funding was insufficient at first to allow the employment of adequate staff personnel to carry out fully the program specified by the 1938 act. With time the engineering staff grew, although initially considerable reliance had to be placed on voluntary cooperation with others in order to develop the Authority's program. OSSA's administration functions were enlarged in 1959 to include the State's air quality control program.

Over the years, OSSA evolved the standards of quality for the public waters of the State from the base established in 1938. During this period, numerous changes in the laws were made to update and strengthen the State program of water quality control.

The Oregon Legislature, on July 1, 1969, replaced the then-existing State Sanitary Authority with the newly created Department of Environmental Quality (DEQ), separate from the OSBH. The DEQ consists of an Environmental Quality Commission, a Director, and professional and support staff. The five lay Commission members are appointed by the Governor, subject to confirmation by the State Senate. The Commission "establishes policy for guidance of the director and staff, reviews and confirms or modified staff actions, adopts rules and regulations, issues orders and authorizes and directs legal enforcement actions".[9]

A STATE POLICY ON WATER POLLUTION

Oregon's first comprehensive pollution control policy was expressed by the water quality control laws passed in 1938. These laws were substantially modified by the State Legislature in 1961 and further changed at each succeeding legislative session. In 1967 these laws were completely rewritten and greatly strengthened. In addition, the standards and programs of the OSSA and DEQ have likewise been dynamic (rather than static) in the sense of changing to meet the altered conditions encountered over the years.

The present policy of the State,[10] as embodied in Oregon Revised Statutes (ORS) Chapter 449 Section 077, first recognizes that "the pollution of the waters of this state constitutes a menace to public health and welfare, creates public nuisances, is harmful to wildlife, fish and aquatic life and impairs domestic, agricultural, industrial, recreational and other legitimate beneficial uses of water" and that "the problem of water pollution in this state is closely related to the problem of water pollution in adjoining states." It is then "declared to be the public policy of the state to:

- conserve the waters of the state;
- protect, maintain, and improve the quality thereof for public water supplies, for the propagation of wildlife, fish and aquatic life and for domestic, agricultural, industrial, municipal, recreational and other legitimate beneficial uses;
- to provide that no waste be discharged into any waters of this state without first receiving the necessary treatment or other corrective action to protect the legitimate beneficial uses of such waters;
- to provide for the prevention, abatement, and control of new or existing water pollution;
- to cooperate with other agencies of the state, agencies of other states and the Federal Government in carrying out those objectives."

The original state policy, established in ORS 449.077 in 1938 and only slightly revised 23 years later by action of the state legislature in 1961, was a considerably more general statement. It reflected the concern of the state and the need for standards of purity but did not mention the specific strategy which later evolved. This strategy is referred to in the present policy with the words "first receiving the necessary treatment or corrective action". The original policy, with slight revision in 1961,[11] was to:

"(a) Maintain reasonable standards of purity of the water of all rivers, streams, lakes, watersheds and the coastal areas of the state consistent with the protection and conservation of the public health, recreational enjoyment of the people, the economic and industrial development of the state, and for the protection of human life and property and conservation of plant, aquatic, and animal life.

(b) Foster and encourage the cooperation of the people, industries, incorporated cities and towns and counties in preventing and controlling the pollution of those waters."

Most significantly, the original 1938 act provided a flexible framework to implement the expressed state policy, a framework which could be modified and updated over time to assure reasonable water purity as conditions in the Willamette Basin changed over the years. This framework to carry out the goals and objectives was embodied in ORS 449.086, which gave the Commission of the OSSA the authority to establish standards of water quality and purity. Hearing procedures were established and responsibility for compliance with standards was clearly stated.

The standards of water quality which the OSSA (and later the DEQ) was to establish, maintain and upgrade thus became the mechanism for the state to achieve pollution abatement, The standards provided a framework against which to judge if pollution abatement was in fact being achieved. They could therefore be used as the means of supporting a pollution control strategy and giving guidance as to the necessary tactics to undertake in order to assure the success of that strategy.

A POLLUTION CONTROL STRATEGY: STANDARDS OF WATER QUALITY AND AT-SOURCE WASTE TREATMENT

The translation of state policy and OSSA mission into accomplishable goals required some type of strategy or guiding course of action. The nature of the strategy had been expressed in the original 1938 act: "...maintain reasonable standards of purity of the water..."

In effect, the water pollution control strategy used by the State of Oregon has been to establish and maintain effective standards of quality and purity for the waters of the state and to require appropriate measures of at-source wastewater treatment so that these standards will be met.

The statutory authority of ORS 449.086 permitted OSSA (later DEQ) to issue Administrative Orders concerning these water quality standards. In 1947 OSSA adopted regulation I entitled "Standards of Purity for Waters of the State of Oregon and General Requirements for the Disposal Therein of Sewage and Industrial Waste". These standards were published under Chapter 340, Oregon Administrative Rules (OAR). In addition to the "Standards" in OAR, Subdivisions of Chapter 340 now include consideration of sewage and waste treatment plant operation, disposal of industrial wastes, construction and use of waste disposal wells, regulations pertaining to waste discharge permits, and state financial assistance to public agencies for construction of pollution control facilities.[12]

The essence of the current water quality standards is to: (a) require the highest and best practicable treatment and control of wastewater; (b) place restrictions on the discharge of sewage and industrial wastes and human activities that affect water quality; (c) maintain the standards of water quality; (d) implement treatment requirements; (e) specify general water quality standards that apply to all State waters; and (f) delineate special water quality standards designed to protect beneficial water uses in specifically designated waters.

The general water quality standards prohibit the discharge of wastes or the conduct of activities which either alone or in combination with other wastes or activities cause effects which deviate from the established criteria. The criteria applicable to surface waters address: dissolved oxygen concentrations; hydrogen ion concentrations; liberation of dissolved gases; fungi and other growths; creation of tastes, odors, toxic or other undesirable conditions; formation of bottom deposits, sludge deposits or other organic or inorganic deposits; objectionable discolorations, turbidity, scum, oily slicks or floating solids; bacterial pollution; temperature increases; offensive aesthetic conditions; and radioisotope concentrations.

Special water quality standards that go beyond the general standards have been applied to several rivers, including the Willamette and some of its tributaries. These set more stringent criteria for measuring dissolved oxygen, Coliform organisms, turbidity, temperature, and dissolved chemical substances.

The water pollution control strategy required that compliance be made with the established standards by appropriate means of controlling waste discharges and related activities at their sources. However, in order to determine what those means might be (i.e., to evolve the tactics that would allow accomplishment of the strategy) it was necessary to measure the condition of the river in comparison with the criteria for desirable water quality. Therefore, the irregular river sampling, carried out in the early 1900's to determine the poor condition of the river, had to be changed in emphasis. Problem areas had to be better pinpointed along the river and the relative influences of various types of waste discharges upon the river condition better understood. This called for routine river sampling. More recently, continuous monitoring was instituted by means of which compliance with the water quality standards could be checked, verification could be made that waste discharges complied with permits regulating those discharges, and violations of the standards could be recognized for enforcement purposes.

Determination of the appropriate measures to accomplish at-source wastewater treatment required an evolutionary period of almost three decades. In effect, this part of the pollution control strategy consisted of a sequence of try-and-see tactics, each going one step further in at-source wastewater treatment, followed by a period of observation of the river condition in order to discover the degree of water quality improvement brought about by the particular tactic. Unfortunately, as far as such an approach was concerned, the Basin population, industrial base and wastewater characteristics did not remain static during the intervening years. Thus, tactics overlapped whenever it became clear that those currently being tried were not closing the "pollution gap" rapidly enough. Consequently, the effectiveness of individual tactics was not always directly measurable.

POLLUTION CONTROL TACTICS: ACTION UNDER THE STRATEGY

The early river sampling surveys had shown water pollution to be severe downstream from the effluent discharges of municipalities along the mainstem Willamette River. Consequently, as the newly formed OSSA began to gather better data on the river's waste loads and water quality there was already enough factual information to form the basis for some immediate actions. Thus, in 1939 the first of over a half-dozen distinct, overlapping tactics was initiated as the OSSA began the "game of catch-up" on Willamette River water quality which was to last for over three decades, until the early 1970's.

Tactic 1: Primary Wastewater Treatment for Mainstem Municipalities

One of OSSA's first actions when its program was started in 1939 was to notify all municipalities and industries of their responsibility under the new law to install adequate sewage and waste treatment facilities.[11] OSSA adopted a regulation which included provision for a minimum dissolved oxygen content of 5 parts per million (PPM) or milligrams/liter (mg/l). It was thought that the early standards of water quality adopted by OSSA could be met if most of the municipalities on the main stem of the Willamette River undertook primary treatment of wastes, followed by effluent chlorination. Primary treatment was considered to mean the removal of not less than 35% of the average 5-day BOD and at least 55% of the suspended solids. Therefore, Tactic 1 was to require mainstem Willamette municipalities to install primary treatment of wastes.

In response to instructions from OSSA, municipalities began in the 1940's to plan for the installation of the necessary treatment facilities. The first compliance with this tactic was in 1949, when primary treatment plants were completed at two cities. By 1957 all municipalities on the main stem of the Willamette River except Portland had complied with the original directive. Portland, with its numerous outfalls for raw wastes, had intercepted most of these outfalls and was providing primary treatment of the intercepted wastes before discharging them directly to the Columbia River, where much greater dilution flows were available.

Evaluation of the effectiveness of this tactic was facilitated when OSSA began routine river sampling in 1950. Periodic surveys were also conducted on a more comprehensive scale. The first comprehensive OSSA survey, in the summer and fall of 1957, showed that the degree of treatment in effect at that time was still insufficient to meet the water quality standards.[11]

Tactic 2: Sulfite Waste Liquor Control by Pulp-and-Paper Mills on the Willamette.

The second tactic was directed toward control. of industrial wastewater discharges from the sizeable pulp-and-paper firms located on the Willamette River. Prior to a public hearing in early 1950, little had been accomplished toward abating pollution from such sources. Sulfite waste liquors entering the river from pulp-and-paper mills between Salem and Portland were reportedly responsible for about 84% of the total pollution load in the river (based on oxygen demand), exclusive of pollutant loads from tributary streams and the city of Portland.[11]

An order was issued by OSSA in May 1950 that the pulp-and-paper mills, by May 1952, cease discharging concentrated sulfite waste liquor into the main Willamette River during July, August, September, and October of each year and at all other times when the Willamette River flow at Salem was less than $200 m^3/s$ (7,000 cfs). An analogous directive applied to a mill responsible for about 91% of the oxygen demand on the South Santiam River.

Therefore, Tactic 2 was to require that particular pulp-and-paper industry wastes that exerted a large oxygen demand be held from the river during those low-flow periods when such a demand could be most deleterious to the river.

In response to this order, the several mills developed plans for special treatment and disposal facilities. The facilities developed included evaporative concentration followed by either burning or spray drying for by-product recovery, impoundment for later release during periods of higher streamflow, and barging of concentrated spent sulfite liquor to the Columbia River for disposal.

The 1957 comprehensive survey of river pollution sources showed that wastes from the sulfite pulp-and-paper mills still represented about 64% of the total oxygen demand of all pollution loads discharged to the Willamette and its major tributaries.

Tactic 3: Selective Secondary Treatment and Accelerated Progress in Primary Treatment

Considerable progress in primary treatment had been made by 1957. In spite of this, certain stretches of the Willamette River fell far short of desirable water quality. The continued increase of population and expansion of industry, together with urban growth that outstripped efforts to provide adequate sewerage facilities, all contributed to the continuation of pollution problems.

The unsatisfactory condition of the Willamette River shown by the 1957 survey led to decisions by OSSA in 1958 which are here represented as tactic 3. These included instructions to the cities of Eugene, Salem and Newberg (each with high industrial waste loadings) to install secondary sewage treatment facilities, the city of Portland to accelerate its program for intercepting and treating raw wastes, and the pulp-and-paper mills to further reduce their pollution loads.

Eugene was able to comply by 1961. Progress for the other cities was slower. Public hearings had to be held, the outcome of which was to set deadlines for compliance with the directive in some instances and a court complaint against Portland which was only dropped after an election vote in 1960 to finance new construction.[11]

Tactic 4: Secondary Treatment for All Lower-Willamette Municipalities

Close on the heels of tactic 3, tactic 4 was implemented in 1960 following a public hearing. The new directive was that all municipalities along the lower Willamette River from Salem downstream were to construct secondary treatment facilities.

The momentum favoring construction of wastewater treatment facilities was showing results. By 1965 compliance with this tactic was essentially complete except for the lower river in Portland, where some raw waste outfalls had not yet been intercepted.

Assessment in 1964

The pollutant load imposed upon the Willamette River appears to have reached its peak in the late 1950's and early 1960's, dependent upon which data are used and location along the river. The 1964 OSSA report on water quality and waste treatment needs for the Willamette utilized prediction curves and procedures developed by Velz for the pulp-and-paper industry to calculate waste treatment requirements to meet the established water quality standards. The OSSA concluded from Velz's work that minimum removals of 85% BOD_5 and settleable solids were required so as to prevent oxygen depletion and sludge deposits in the river. Effluent chlorination continued to be essential. Further, it was determined that any significant increases in waste loads would require even greater reductions of oxygen demanding substances and settleable solids if acceptable water quality in the Willamette River was to be achieved and maintained. In spite of all the municipal and industrial wastewater treatment facilities installed by 1963, the water quality of the Willamette River "was still considerably below the standards set by the Sanitary Authority".[11]

Tactic 5: General Secondary Treatment and Year-Around Primary Treatment at Pulp Mills

The assessment of Willamette water quality in 1964 by OSSA resulted in tactic 5. This required: (a) year-around primary sedimentation or equivalent treatment for removal of settleable solids for all industrial wastes from each pulp-and-paper mill; (b) the additional requirement at each sulfite pulp-and-paper bill;during the period of critical river flow from June to October, inclusive, for an overall reduction of 85% in BOD loadings of effluents from the entire mill; (c) a minimum of secondary treatment, or equivalent, from all other sewage or waste effluents to provide not less than 85% BOD removal and to include chlorination for sewage effluents; (d) an even higher degree of sewage and industrial waste treatment in some cases (depending on size and nature of waste load and receiving stream); and (e) a deadline of December 1, 1966, to install the needed treatment facilities.

Although the December 1966 deadline was not met by all of the affected companies, sufficient progress was made so that in 1967 a significant change in Oregon's water quality control laws was made which changed the emphasis from pollution abatement to pollution prevention and water quality enhancement.[9] The signs pointed to successful achievement of the pollution control strategy within the near future. There remained, however, several measures or tactics to implement in order to assure the success of this strategy.

Tactic 6: Secondary Treatment Established as Minimum Level

As a modification of tactic 5, tactic 6 was established in 1967 requiring all wastewater discharged into any of Oregon's public waters to receive a minimum of secondary treatment. Provision was made that levels higher than conventional secondary treatment might be required, in which case the standards would include specific treatment requirements and effluent limits. Year-around secondary treatment for Willamette Basin dischargers was scheduled to be in effect prior to the 1972 low-flow season.[9]

Tactic 7: Specific Waste Discharge Permits

Another significant tactic to promote and protect the pollution control strategy was the introduction in 1968 of the waste discharge permit, required for any wastes discharged into the public waters of the state. The permits contain definite limitations on quantities and strengths of wastes that could be discharged. Characteristically, numerical limits are included on pounds of BOD and suspended solids, pH, bacteria, temperature, color, turbidity, and toxic elements. In cases where treatment or control is inadequate at the time of permit application, a specific, detailed program and timetable to achieve fully adequate treatment is included in the permit.[9]

By 1968, all major and many minor point-source waste discharges had been identified. The permits provided OSSA (and now DEQ) with an effective mechanism to inventory _all_ waste discharges to state waters. These permits also provide an effective means of regulation of the waste load entering these waters over time.

Supporting Tactics

While seven specific actions to achieve the pollution control strategy have been identified and even given a chronological number, many supporting actions and tactics have also been used by OSSA and, since July 1969, by DEQ to achieve water quality control.[9] These include:

- promotion of the idea of water pollution control;
- promotion of the installation of public sewer systems and wastewater treatment and control facilities;
- review and approval of plans and specifications for all wastewater treatment and disposal projects;
- stream monitoring for pollution control;
- comprehensive stream surveys to study pollution problems;
- inspection and efficiency tests of wastewater treatment plants;

- training of wastewater treatment plant operators and staff;
- separation of storm and sanitary sewer waters to reduce treatment plant loads and prevent bypassing of sewage flows at times of high runoff;
- basic data collection on water quality;
- investigation of complaints and holding of public hearings;
- enforcement of the pollution control laws, regulations, and permit conditions;
- processing of applications for Federal and State sewage works construction grants;
- State construction grants program for sewage works;
- certification of industrial waste control facilities for tax credits; and
- a tax relief program.

Results of the Strategy and Tactics

The pollution control strategy of establishing standards of water quality and requiring appropriate measures of at-source wastewater treatment to meet these standards was supported by numerous tactics and related actions. By 1970 it was apparent that the strategy was achieving success, even though the full effects of some then-ongoing tactics were not yet evident. The municipal and industrial waste loads entering the Willamette River had been drastically cut in terms of absolute amounts. While waste concentrations tended to be influenced by the degree of summer augmentation of river flow from reservoir storage, the absolute loading directly demonstrated that river pollution had been controlled and reduced. Municipal waste discharges (including industrial waste components) during the 1970 low river flow season were reduced 89% on an overall basis and industrial waste discharges were reduced 86% overall.[9] Both the municipalities and the industries of the Willamette Basin have been assigned essentially fixed limits of BOD discharges by the DEQ, so that future growth and development must be accompanied by increased treatment efficiency with no increase of the waste load entering the river.

RELATED FEDERAL STRATEGIES AND TACTICS

Passage of PL 80-845, the Federal Water Pollution Control Act, by the U. S. Congress in 1948 drew the Federal government into post-war pollution control planning in the Willamette Basin. The Federal strategy at that time appears to have been one of stimulating cooperative action among Federal, state, local and private groups to formulate comprehensive programs for water pollution control that would conserve a broad range of beneficial uses on interstate waters and their tributaries. One result of this act was a report by the U. S. Public Health

Service, in cooperation with OSSA, on water pollution control in the Willamette Basin. This report, based on data available in 1950, was intended as a reference point for measuring future progress in pollution control and as a basis for developing comprehensive plans and financial assistance programs.[14]

A critical constraint upon the rate of progress in solving the pollution problems in the Willamette River was the limitation of adequate financing for sewerage and sewage treatment facilities. Voter approval was required to finance the majority of such community projects. Financing came from borrowed money obtained through the sale of general obligation bonds, direct property assessments, and sinking funds accumulated by special tax levies or sewer rental charges. Private industry financed its waste control from internally derived funds. Prior to 1956, no Federal assistance programs were available to influence the pace of water pollution control for the Willamette River.

In July 1956 Congress passed Public Law 84-660, the 1956 Federal Water Pollution Control Act, which included a ten-year program of financial assistance to communities for construction of sewage treatment works. This covered only a portion of the total costs, but encouraged and extended the effectiveness of state and local funding. In Oregon, the OSSA had responsibility for reviewing and approving applications for grants and for assigning project priorities based on financial and water pollution control needs. The 1956 act was amended in 1961 and 1965 to increase the appropriations for construction of wastewater treatment facilities and to extend the period of the program.

During the 1960's, other Federal grant programs came into being to finance the construction of sewer systems and sewage treatment facilities. These required cost-sharing by state and local participants. As with the Water Pollution Control Act, these programs significantly aided in spreading the financial burden and stimulating new construction.

The 1956 Federal Water Pollution Control Act and its subsequent amendments provided for comprehensive water pollution control programs, including a review of the water quality control benefits of proposed Federal reservoirs. As had the earlier 1948 act, the 1956 act and amendments served to encourage the ongoing efforts of OSSA to control water pollution in the Willamette River.

On a more sweeping basis, the Federal Water Quality Act of 1965 (PL 89-234), added vitality to pollution control efforts in the Willamette Basin. This Federal legislation required that states adopt water quality standards and enforceable implementation plans to assure waste treatment measures that would control sources of water pollution. The Federal government also took a more active role in the Basin's water quality management, joining forces with the State to develop a wide-ranging pollution control program in 1967.[15] Oregon already had water quality standards and implementation programs to provide waste treatment facilities. The 1965 amendments to previous Federal water pollution control legislation led Oregon to revise and update its general and special water quality standards in 1967. These new standards were among the first approved by the Federal government, thereby becoming also Federal standards subject to Federal enforcement.

In retrospect, Federal activities aimed at pollution control by means of at-site waste treatment have been significant in the Willamette Basin for their support rather than guidance of State policy. The State and its electorate made its commitment to pollution control in 1938 and provided leadership for guiding state policy by creation of the State Sanitary Authority. But the road to success was difficult and the financial burdens heavy. The Federal grants for waste control facilities brought financial support during critical years of population and industrial growth when a slower-paced program would have made it very difficult to make gains against water pollution; Beyond financial support, the Federal concern over State water pollution problems exerted its influence over State water policy in other ways, among these being the stimulus for new water quality standards in 1967 and the beneficial effects of cooperative programs. The U. S. Public Health Service, for example, was an active cooperator with the State in data gathering and other ways early in the century and has remained so over the years, along with newer Federal organizations.

AN OLD STRATEGY UPDATED: WASTE DILUTION BY FLOW AUGMENTATION

The traditional method of waste disposal practiced over centuries by riverbank communities was to release untreated wastes directly to streams, thereby diluting the strengths of such wastes and, hopefully, allowing them to be assimilated by the receiving waters. This approach was used by communities and industries along the Willamette River well into the 1950's, even though adverse pollutional effects had been evident for decades. The waste dilution method was even refined in the lower river to the extent that certain industrial wastes were being barged to the Columbia River for dumping, where the diluting flow available was more than an order of magnitude greater than in the Willamette. Even Portland, after giving primary treatment to sewage flows, was releasing these wastes to the Columbia River rather than applying secondary treatment before releasing effluent to the Willamette River. But the old standby method of waste dilution failed in the face of population and industrial growth in the Willamette Basin.

The same growth of population and the industrial base that aggravated the severe water pollution problems brought with it other needs, such as flood control. Measures taken to alleviate flood control led to construction and operation of Federal storage reservoirs by the U. S. Army Corps of Engineers. These became the means for a new strategy in the battle against water pollution--waste pollution control by means of flow augmentation and the resulting dilution of wastewaters.

Over the years, the OSSA and DEQ, in their biennial and annual reports, have cited the pollution control benefits gained in the Willamette River because of summer streamflow regulation by release of impounded waters from upstream storage reservoirs. For instance, the 1960 report recognized that maintaining a reasonable degree of purity in the Willamette River along with future population and industrial growth make it absolutely essential that flows be augmented considerably in the lower Willamette during the critical summer and fall months. Such augmentation was considered to be a "supplement to and not as a substitute for sewage and waste treatment."[3]

The reservoirs were not constructed for water quality enhancement; their authorized purposes were flood control, navigation, irrigation, and hydroelectric power generation (see Table 2). However, because of the hydrologic conditions in the Willamette Basin, the same influences that caused low-flow problems in the summer months also minimized the risk of summer floods and required significant releases of stored water for irrigation and navigation. This compatability between the authorized purposes, particularly navigation, and the need for more water in the river to enhance water quality has made possible an effective pollution control strategy--flow augmentation for waste dilution.

The plan for multi-purpose Federal storage reservoirs on the major tributaries of the Willamette River was conceived in the early 1930's. In the reports recommending authorization of individual projects, "water quality flow needs were recognized, and it was stated that the navigation flows of 6,000 cubic feet per second at Salem would provide for the water quality needs. Since that time, water quality management of the basin has been based upon the continued availability of those flows to meet navigation needs."[9] However, the Federal agencies involved in Willamette Basin water planning recognized, as had OSSA, that "the basic element of the water pollution control program is a high level of at-source waste treatment by all municipalities and industries."

The early Federal storage reservoirs in the Willamette Basin were comparatively small and had little effect on summer low-flow water quality. However, larger impoundments were completed starting in the early 1950's (see Figure 6) and the amount of storage water released to augment low natural flows began to have a noticeable effect thereafter. By 1968, 13 Federal projects were complete and providing flow augmentation benefits.

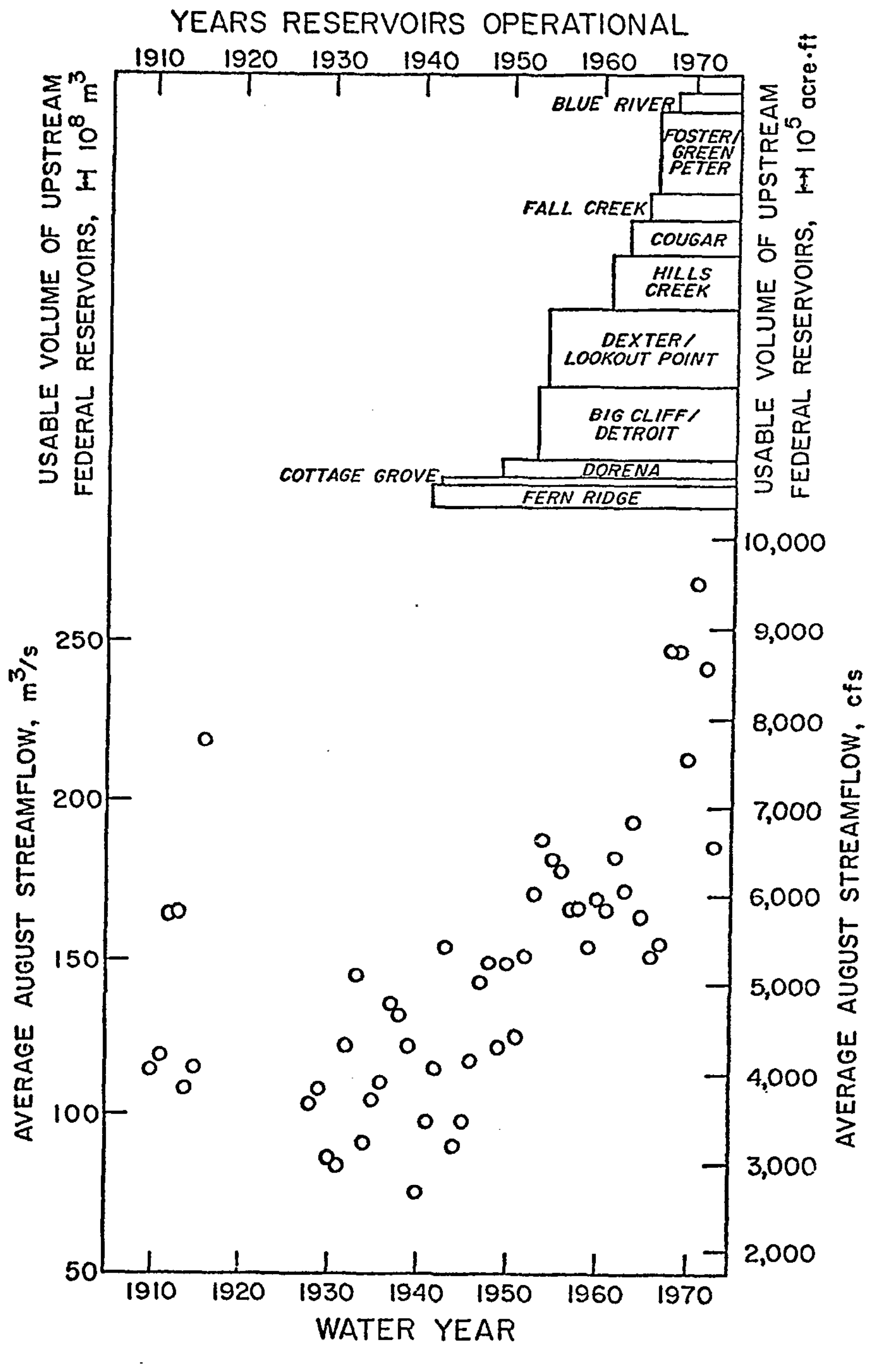

Figure 6. Average August streamflows at Salem and upstream federal reservoirs.

Using the dry month of August as a basis for comparison, average monthly discharge at Salem is shown in Figure 6 over the period of years of record. Allowing for year-to-year climatic variability, it is quite clear that impoundment releases in recent years have had a dramatic effect in increasing the amount of water in the river and in diluting wastes. In some years more than half of the August streamflow in the Willamette River has been from impoundment releases.

RELIANCE ON TWO STRATEGIES

The strategy adopted by the State of Oregon to set water quality standards and require compliance by means of at-source waste treatment was absolutely essential and has been proven effective. The absolute load of pollutants entering the Willamette River has been reduced and brought under control. This has also achieved a substantial change in the concentrations (i.e., relative amounts) of the various indicators of water quality, such as dissolved oxygen.

But during critical summer-autumn months of low natural streamflow, the measures taken to date to achieve at-source pollution control would not have been sufficient alone. The water quality standards have been met during some critical low-flow periods only because the river flow was substantially augmented from storage releases. In recent years, this augmented flow has been well above the target flows (e.g., above the $170 m^3/s$ (6,000cfs) minimum flow at Salem). Therefore, it is evident that without more stringent requirements controlling the treatment of at-source pollution, the flow augmentation strategy is also essential. Data from recent years show that it has been an effective strategy.

In effect, there must presently be a reliance upon two pollution control strategies for the Willamette River: the first, guided and enforced by the State, requiring at-source waste treatment to reduce the absolute pollutant loadings; the second, under the control of the Federal government, requiring flow augmentation during critical low-flow months to reduce the concentration and strength of pollutant loadings. Jointly, these strategies allow the water quality standards of the State to be met. Without the first, at-source treatment, no practical amount of flow augmentation from existing multi-purpose reservoirs would be sufficient to allow the standards to be met. Without the second, flow augmentation, the degree of at-source waste removal would have to be greatly increased and new technologies beyond secondary treatment would be required.

SECTION VI

ENVIRONMENTAL IMPACTS

SCOPE OF IMPACTS

The cumulative environmental impacts of the pollution control strategies used for the Willamette River are broad and difficult to quantify. They touch human activities in a number of ways, some of which are describable collectively as altered quality of life, insofar as the Willamette River has an influence on an individual's interests and activities. For example, a recent study[16] showed that the substantial improvement of the Willamette River water quality led to increases in values for urban residential property as far as 1200 m (4000 ft) away from the water's edge. Interestingly, the wildlife support capacity of water bodies was valued more by residential property owners than were aesthetics, boating, or swimming. The measurable water quality parameters reported to have the greatest influence on property values were dissolved oxygen, fecal coliforms, clarity, trash and debris, toxic chemicals, and pH.

Some of the cumulative environmental impacts of at-source waste treatment are of a "trade-off" nature. The benefits gained by removal of contaminants from the water phase of the environment are offset by their disposal in some other phase of the environment. This can result in air pollution (through combustion of sludge or gases) and land pollution (through landfilling of residual sludges) which in turn can lead to water pollution. In-process changes made by some industries to reduce pollutant loads in effluents, such as the conversion of sulfite pulp-and-paper mills from one base to another to facilitate chemical recovery, have resulted in increased stack emissions from recovery boilers. Additional environmental contamination results from the production, transportation/transmission, and utilization of energy needed to drive all of the wastewater treatment processes and to produce the chemicals used in wastewater treatment. Such secondary impacts can cause significant environmental effects at locations distant from the treatment plants, often outside the Willamette Basin.

Wastewater treatment requires large tracts of land for the facilities themselves and for solid residue disposal; for municipalities this land represents a reduction in the tax base. In addition to odors and noise associated with the plant operation, some facilities are aesthetically displeasing. Adverse impacts such as those mentioned here must be weighed against the substantial benefits to river water quality evidenced by restored high oxygen levels and reductions in bacterial contamination, suspended solids, floating matter, and toxic chemicals.

Flow augmentation also has associated with it a number of trade-off environmental impacts. In downstream reaches below impoundments, the majority of impacts are regarded as beneficial, although the reduced summer temperatures of some releases and the diminished variability of flows can present adverse impacts such as less desirable swimming temperatures and less natural control over some aquatic vegetation and insects by periodic flooding. Improved navigation conditions can result in associated increases of boat-related forms of pollution. Greater flood control protection of the floodplain can lead to greater floodplain encroachment.

At the reservoirs and along adjacent reaches of the river, there may be additional environmental tradeoffs. Creation of a slack-water fishery and lake recreation is done at a loss of free-flowing fishery and stream recreation. Loss of one type of wildlife habitat is replaced by creation of a different type of habitat. Release of impounded water in the summer for flow augmentation represents a loss of impounded water needed for autumn hydroelectric power generation to supplement power produced elsewhere in the Columbia River Basin. This trade-off is partly offset by heavier reliance on non-power producing reservoirs such as Blue River and Fall Creek for summer flow augmentation. But impoundment releases for flow augmentation during the summer from additional non-power projects such as Dorena and Cottage Grove meets with greater resistance from recreationists using those reservoirs.

The "health" of a water body and extent of pollutional effects are often best reflected and measured by the performance of the bio-system. For the Willamette River, the part of the bio-system about which the most is known historically is the fishery, particularly the salmonid fishery. This anadromous fishery happens to be a particularly sensitive indicator of water quality conditions. Therefore, to document the cumulative environmental impacts of the pollution control strategies used for the Willamette River, detailed examination has been made of the Willamette River fishery.

HISTORICAL

The Willamette Basin undoubtedly was rich in certain natural resources prior to the 19th Century. Craig and Hacker[17] estimate that the Columbia Basin supported a population of 50,000 Indians who annually harvested 8 million kg (18 million lb) of salmon. Willamette Falls was identified as one of the historically famous Indian fishing sites.[1] Other wildlife forms such as cougar, river otter, muskrat, beaver, and migrating ducks and geese were thought to be more abundant before the year 1800 than at any subsequent time.

Commercial fishing for salmon began in the lower Columbia River region in the early 1800's. By 1830, several dealers were salt-curing salmon on the lower Willamette River for export.[19] Commercial canning of salmon began on the lower Columbia River in 1866 and increased rapidly to a record pack of 634,696 cases in 1895.[20] The record catch of salmon and steelhead occurred in 1911 when 21,117,000 kg (46,663,000 lb) were landed.[21]

In addition to salmon and steelhead, other Willamette fish harvested commercially were shad, sturgeon, eulachon (smelt) and lamprey. Of equal importance to the Willamette Basin were the recreational species and fisheries. Trout, primarily rainbow and cutthroat, were so abundant that the early bag limit was 125 fish per day. Warm-water game fishes such as largemouth and smallmouth bass, black and white crappie, bluegill, and pumpkinseed were introduced around the turn of the 19th Century and prospered in the sloughs and ponds of the Willamette Basin.[22]

During the 1800's, several wildlife species were affected by the activities of the early settlers. Logging and land-clearing benefitted the blacktailed deer, while mourning dove, band-tailed pigeon, ducks, and geese found the development of agriculture to their liking. Pheasants, valley quail, and bobwhite quail were introduced and increased rapidly. Other species were not so fortunate as the impact of unrestricted hunting and trapping severely reduced populations of beaver, river otter, and cougar.

Recognition of serious pollution in the lower Willamette River was a matter of public record as early as 1910 when Morse _et al._[23] stated in their Fourth Biennial Report of the State Board of Health that: "... they become a conduit into which in increasing quantities in direct proportion to the increasing density of the population, along their banks is cast offal and filth until nearly all of the streams of the State have become mere sewers, the water from which is not only dangerous to drink but too filthy in many places to bathe in. Even the very fish which have no means of escape are largely becoming infected and unfit for food. This condition is rapidly growing worse and has become a peril of no mean import, and is a grave reflection upon the intelligence and degree of civilization of the entire community and should be stopped at once and forever."

Subsequently, the so-called oxygen blockage in the lower Willamette River has been documented and studied repeatedly, as described earlier in this report. In particular, the reports by Gleeson[7] and Willis _et al._[24] are informative. The presence of water with oxygen levels below 5 mg/l for prolonged periods during July, August, and September, coupled with inadequate fish passage facilities at Willamette Falls, were believed to be important reasons why few coho salmon and fall chinook salmon occurred beyond the reaches of the lower Willamette River area.[24,25]

CURRENT STATUS OF THE WILLAMETTE FISHERY

The Willamette Basin contains from 14,000 to 16,000 km (9,000 to 10,000 mi) of streams, at least 565 named lakes, and approximately 130 mega square meters (Mm2) (33,000 acres) of reservoirs.[19] Of this total, most production in fluvial habitats occurs in 6788 km (4219 mi) of streams comprising 196 Mm2 (48,600 acres) of water. Stream widths greater than 100m (300 ft) comprise 10 percent of the length and 57 percent of the total surface area; whereas, streams less than 1 m (4 ft) in width comprise 27 percent of the length but only 1.1 percent of the surface area.[26]

Some 51 species belonging to 14 families comprise the fish fauna of the Willamette Basin. At least 28 species are of recreational or commercial importance. Almost one-half of the species (23) have been introduced into the basin during the past 100 years (see Table 5). Distributions of the salmonids and some of the warm-water game fishes within their principal habitats in the Willamette Basin are provided in Tables 6, 7, and 8.

Several recent reports give detailed descriptions of the current status of the fishery and wildlife resources of the Willamette Basin. One of the most extensive and detailed surveys of the Willamette River and its tributaries was conducted by Willis _et al._[24] Their report includes the following information on each river system: a brief introduction; descriptive information concerning the basin, stream, bottom material, obstructions, diversions, and pollution problems; impoundment and hatchery sites; temperature and flow data; anadromous fish populations; and major proposed dams. A summary of recommendations was presented for the entire Willamette River system wherein the proposed projects were listed in order of priority or importance without reference to costs or estimates or responsibility.

More recently details of the middle Willamette Basin were provided by the Oregon State Game Commission; those of the lower Willamette Basin were provided by Hutchison and Aney[28]; while those of the upper Willamette Basin were detailed by Hutchison _et al._[29] Thompson _et al._[27] combined much of the information on fishery resources from the above three reports into "Fish Resources of the Willamette Basin", which was submitted to the Willamette Basin Task Force. In turn, the information provided by the above four sources was combined and published as Appendix D, Fish and Wildlife, to the Willamette Basin Comprehensive Study of Water and Related Land Resources.[19]

A more generalized review of the fish and wildlife resources of the Willamette River watershed, including the Sandy River watershed, was published as Appendix XIV, Fish and Wildlife, to the Comprehensive Framework Study of Water and Related Lands.[30] This latter report contains useful information on fish and wildlife Angler-Days and Hunter-Days

Table 5. FISHES OF THE WILLAMETTE BASIN[a]

Scientific name	Common name	Abundance
Petromyzontidae		
Entosphenus tridentata	Pacific lamprey	High
Lampetra richardsoni	Western brook lamprey	High
Acipenseridae		
Acipenser transmontanus[b]	White sturgeon	Moderate
Clupeidae		
Alosa sapidissima[b,c]	American shad	High below Willamette Falls; low above falls
Salmonidae		
Oncorhynchus keta[b]	Chum salmon	Low
Oncorhynchus kisutch[b]	Coho salmon	Moderate
Oncorhynchus nerka[b,c]	Sockeye salmon or kokanee	Low
Oncorhynchus tshawytscha[b]	Spring chinook and Fall chinook salmon	Moderate to high Moderate
Prosopium williamsoni[b]	Mountain whitefish	Low to moderate
Salmo aguabonita[b,c]	Golden trout	Low
Salmo clarki[b]	Cutthroat trout	High
Salmo gairdneri[b]	Rainbow (steelhead) trout	Moderate
Salmo salar[,c]	Atlantic salmon	Low
Salmo trutta[b,c]	Brown trout	Low
Salvelinus fontinalis[b,]	Brook trout	Low
Salvelinus malma[b]	Dolly Varden	Low
Salvelinus namaycush[b,c]	Lake trout	Low

Table 5 (continued). FISHES OF THE WILLAMETTE BASIN[a]

Scientific name	Common name	Abundance
Cyprinidae		
Acrocheilus alutaceus	Chiselmouth	High
Carassius auratus[c]	Goldfish	Low
Cyprinus carpio[c]	Carp	High
Hybopsis crameri	Oregon chub	Low
Mylocheilus caurinus	Peamouth	Moderate
Ptychocheilus oregonensis	Northern squawfish	High
Rhinichthys cataractae	Longnose dace	High
Rhinichthys falcatus	Leopard dace	High
Rhinichthys osculus	Speckled dace	High
Richardsonius balteatus	Redside shiner	High
Tinca tinca[c]	Tench	Low
Catostomidae		
Catostomus macrocheilus	Largescale sucker	High
Catostomus platyrhynchus	Mountain sucker	High above Corvallis; low in downstream areas
Ictaluridae		
Ictalurus melas[b,c]	Black bullhead	(Unauthenticated reports)
Ictalurus natalis[b,c]	Yellow bullhead	Moderate
Ictalurus nebulosus[b,c]	Brown bullhead	Moderate
Ictalurus punctatus[b,c]	Channel catfish	Low to moderate
Percopsidae		
Percopsis transmontana	Sand roller	Low to moderate
Poeciliidae		
Gambusia affinis[c]	Mosquitofish	Low to moderate

Table 5 (continued). FISHES OF THE WILLAMETTE BASIN[a]

Scientific name	Common name	Abundance
Gasterosteidae		
Gzsterosteus aculeatus	Threespine stickle-back	High
Centrarchidae		
Lepomis gibbosus[b,c]	Pumpkinseed	High
Lepomis gulosus[b,c]	Warmouth	High
Lepomis macrochirus[b,c]	Bluegill	High
Micropterus dolomieui[b,c]	Smallmouth bass	Moderate
Micropterus salmoides[b,c]	Largemouth bass	High
Pomoxis annularis[b,c]	White crappie	High
Pomoxis nigromaculatus[b,c]	Black crappie	High
Percidae		
Perca flavescens[b,c]	Yellow perch	High
Cottidae		
Cottus asper	Prickly sculpin	Low
Cottus bairdi	Mottled sculpin	Low
Cottus beldingi	Piute sculpin	Moderate
Cottus perplexus	Reticulate sculpin	Moderate
Cottus rhotheus	Torrent sculpin	Low

[a] Modified from reference 27.

[b] Species defined as "game fish" in the 1965-66 Oregon Game Code.

[c] Introduced species, all others are indigenous to the Willamette Basin.

Table 6. DISTRIBUTION OF PRINCIPAL SALMONIDS INHABITING LAKES, RESERVOIRS, SLOUGHS, OR PONDS IN THE WILLAMETTE BASIN[a]

Species	Number of lakes inhabited[b]	Surface area, 1000 m^2,[c] inhabited[d]	Hatchery contribution,[e] percent
Brook trout	34	15,870	50
Cutthroat trout	37	68,696	11
Dolly Varden trout	8	8,101	0
Kokanee	13	14,090	77
Lake trout	0	0	0
Rainbow trout	48	70,177	92
Chinook salmon (L)[f]	13	34,864	62
Coho salmon (L)[f]	8	11,600	100
Steelhead (L)[f]	9	10,170	33

[a] Data from reference 26.

[b] 78 lakes available.

[c] $1000 m^2$ = 0.247 acres.

[d] 78,489,000 m^2 available.

[e] Percent of lakes in which any portion of species are of hatchery origin.

[f] L indicates Landlocked populations only.

Table 7. DISTRIBUTION OF PRINCIPAL ANADROMOUS SALMONIDS INHABITING RIVERS AND STREAMS IN THE WILLAMETTE BASIN[a]

Species	Streams inhabited[b]	Stream length, km,[c] inhabited[d]	Estimated population
Fall chinook salmon	41	1,150	7,600
Spring chinook salmon	64	2,016	34,000
Coho salmon	147	3,313	17,000
Summer steelhead	33	1,130	660
Winter steelhead	127	3,181	16,000
Sockeye salmon	17	553	200
Sea-run cutthroat trout	31	677	68

[a] Data from reference 26.

[b] 290 streams available.

[c] 1 km = 0.621 mi.

[d] 6,668 km available.

Table 8. DISTRIBUTION OF CERTAIN WARM-WATER GAME FISH INHABITING RIVERS AND STREAMS IN THE WILLAMETTE BASIN[a]

Species	Streams inhabited[b]	Stream length, km,[c] inhabited[d]	Abundance
Black crappie	12	351	Common
White crappie	36	938	Few
Largemouth bass	39	912	Few/rare
Smallmouth bass	2	61	Rare

[a] Data from reference 26.

[b] 290 streams available.

[c] 1 km = 0.621 mi.

[d] 6,668 km available.

which are summarized in Table 9. Information is also provided on non-game wildlife along with projections of future needs to satisfy the demand for use of fish and wildlife resources within the Willamette Basin.

In summarizing the current status of the resource, it appears that stocks of spring chinook salmon have stabilized at 30,000 to 40,000 escapements over Willamette Falls. Stocks of spring chinook salmon returning to the Clackamas River appear to have decreased in recent times from about 3,000 to 2,000 fish per year (Figure 7). Based on an average fecundity of 5,000 eggs and a 50:50 sex ratio, the Clackamas River run must have contained a minimum of 6,000 fish around the turn of the century. The runs of spring chinook salmon are heavily supported with releases from hatcheries.

Escapements of coho salmon past Willamette Falls have decreased markedly in the past four years (Figure 8). On the other hand, escapements of fall chinook salmon (Figure 8) and summer and winter steelhead (Figure 9) are all on the increase. Overall, the sport catch of salmon and steelhead in the Willamette Basin is on the increase as well as in the State as a whole (Figures 10,11).

Overall, stocks of resident trout appear to be greatly reduced from earlier years, but liberal supplements with hatchery fish help maintain heavy angler use (Table 9). Virtually no stocking of warm-water game fish is carried out as natural stocks seem sufficient for substantial angler use (Table 9).

ENVIRONMENTAL IMPACTS

Benefits

Anadromous fish resources are obvious beneficiaries of water quality improvements in the lower Willamette River. Waters with less than 5 mg/l of dissolved oxygen are generally thought to block or delay the passage of migrating salmonids.[7] Sams and Conover[25] presented data indicating that runs of coho and fall chinook salmon did not attempt to pass over Willamette Falls until dissolved oxygen levels exceeded 4 mg/l. Based on data depicted in Figures 12 and 13, the lower 50 miles of the Willamette River apparently served as an oxygen blockage to migrating salmon during much of July, August, and September from the 1920's to 1968. From 1968 to present, the mean dissolved oxygen concentration during the critical month of August was never below 5 mg/l at the Spokane, Portland and Seattle Railroad bridge--an area thought to be one of the most seriously polluted sections of the River. Whether the increase in dissolved oxygen was due to municipal and industrial waste treatment or to augmented flow of the River is a matter of conjecture (Figure 13).